Nonlinear effects in WCDMA systems

Information here is taken from [1]. Key UMTS (FDD) specifications:

Access method: DS-CDMA	Duplex procedure: FDD
Modulation: QPSK	Pulse shaping: Root-raised cosine, α = 0.22
Chip rate: 3.84 Mcp/s	User data rate: 384 kb/s (up to 2 Mb/s indoors)
Bandwidth/channel: 5 MHz	Max. output power: 21 dBm

User data rate can start at 12.2 kbps. The uplink uses a more complicated hybrid QPSK modulation method to minimise amplitude variations of transmitted signal. With a user bit rate of 12.2 kbps, the bit error rate should be below 10^{-3}, for which E_b/N_t = 5.2 dB, and E_b/N_t = 7 dB with baseband implementation margin is needed. The processing gain is given as:

$$G_P = 10 \cdot \log_{10}\left(\frac{\text{chip rate}}{\text{user data rate}}\right)$$

CDMA signal high crest factor (can range from 4.5 to 11 dB, depending on the number of code channels):

$$\xi = 10 \cdot \log\left(\frac{P_{\text{PEAK}}}{P_{\text{AVERAGE}}}\right)$$

where

P_{PEAK} is the 99.9% limit of the instantaneous-power distribution
P_{AVERAGE} is the mean power of the signal.

Compared to sinusoidal signals (ξ = 3 dB), CDMA signals require higher linearity to prevent compression or clipping of the signal.

Adjacent channel leakage ratio

Adjacent channel leakage ratio (ACLR) is defined as:

$$\text{ACLR} = 10 \cdot \log\left(\frac{P_{\text{ADJACENT}}}{P_{\text{WANTED}}}\right)$$

where

P_{ADJACENT} is the power in the adjacent channel
P_{WANTED} is the power in the wanted channel.

This effect occurs with broadband signals and it is caused by the odd terms of the transfer function of the building block. The cubic term in the nonlinearity causes a broadening of the spectrum to approximately three times of the original bandwidth [5-4], thus leaking into the lower and upper adjacent channel.

The following approximate formula for ACLR can be obtained, and it works well especially for higher P_{in} values:

$$\mathrm{ACLR} = -20.75\,\mathrm{dB} + 1.6\xi + 2\left(P_{\mathrm{in}} - IIP3_{\mathrm{SINE}}\right)$$

Adjacent channel selectivity (ACS) is a measure of receiver’s ability to receive a WCDMA signal at its assigned frequency in the presence of an adjacent channel signal at a given frequency offset. Adjacent channel selectivity is the ratio of the receive filter attenuation on the assigned channel frequency to the receive filter’s attenuation on the adjacent channel. In general, ACS should be better than 33 dB, BER < 10^{-3}.

1 dB compression point

The cubic part of the nonlinearity also leads to the saturation of the output power, commonly described by the 1 dB compression point P_{1dB}. For systems with weak nonlinearity the following approximation can be used:

$$P_{\mathrm{1dB,SINE}} \approx IIP3_{\mathrm{SINE}} - 10\,\mathrm{dB}$$

Measurements suggest that for a large number of code channels (more than 8):

$$P_{\mathrm{1dB,CDMA}} \approx P_{\mathrm{1dB,SINE}} - 3\,\mathrm{dB} = IIP3_{\mathrm{SINE}} - 13\,\mathrm{dB}$$

This effect is caused by the high crest factor of the CDMA signal.

Cross modulation

Cross modulation is caused by the transfer of the amplitude modulation of a strong signal (like the transmitter in a handset) onto another signal (the adjacent channel) in a nonlinear processing block (i.e. the LNA).

Cross modulation and ACLR are very similar effects. The difference is that ACLR is caused by only one large signal and cross modulation causes leakage of a smaller signal into its adjacent channels. This leakage is induced by a large signal.

For the CDMA receiver discussed in [7-6] a calculation of the single-sideband cross modulation power is shown:

$$P_{\mathrm{CMOD}} = k_{\mathrm{CMOD}} + 2\left(P_{\mathrm{TX}} - IIP3\right) + P_{\mathrm{ADJ}}$$

where

P_{CMOD} is the cross modulation power in the user channel
P_{ADJ} is the adjacent channel power
P_{TX} is the transmitter power at the input of the LNA (including duplexer isolation)

k_{CMOD} (in dB) is an empirical factor that accounts for the crest factor of the modulation and for signal bandwidth.

If is often the cross modulation that determines the required IIP3 of the LNA in a mobile WCDMA receiver.

This is a very important issue in UMTS receivers because the transmitter can be active during reception and the high output power (up to +21 dBm) is only filtered by the duplexer filter in front of the LNA. Additionally, it is possible that the adjacent channel is 41 dB stronger than the wanted channel.

Third-order intermodulation

Intermodulation products are broadened to roughly three times the bandwidth of the WCDMA signal. Due to the spreading of the intermodulation product, less power is overlapping with the wanted channel (roughly 2/3 of the total IM power falls into the user bandwidth).

This can be accounted for by introducing an IIP3 for WCDMA signals, which is a little bit higher than the IIP3 found by measuring blocks with sinusoids:

$$IIP3_{\mathrm{CDMA}} \approx IIP3_{\mathrm{SINE}} + 0.9\,\mathrm{dB}$$

Second-order intermodulation

Even terms of the transfer function cause second-order intermodulation [8-7]. Zero-IF receivers are handicapped by this kind of interference to a large extent, especially when receiving strong amplitude-modulated signals (like in WCDMA).

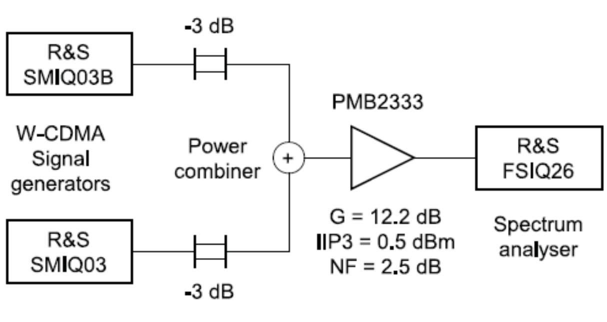
Large, closely spaced interferes also produce strong second-order intermodulation close to the baseband. Achieving a high IIP2 is crucial for the successful implementation of a WCDMA zero-IF receiver.

The intermodulation product in the base band has twice the bandwidth of the modulation signal. Calculations very similar to $IIP3_{CDMA}$ suggest:

$$IIP2_{\mathrm{CDMA}} \approx IIP2_{\mathrm{SINE}} + 1.25\,\mathrm{dB}$$

Measurement setup

A sample measurement setup is shown in **Error! Reference source not found.**.



References

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Version history

Version 1 (29 OCT 2008): First release.