

Conformance Metrics and Evaluation of HSDPA Systems with RF Impairments in Next Generation Wireless Standards

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Abstract — High Speed Downlink Packet Access (HSDPA) is a service extension for the Universal Mobile Telecommunications System (UMTS) Wideband Code Division Multiple Access (W-CDMA) standard that delivers higher data rates with lower latency and increased network capacity. The design of such systems requires that they perform within specified bounds in terms of numerous transmitter and receiver metrics such as spectral content, error vector magnitude (EVM), and bit-error-rate (BER) in various channel conditions and interference environments. We provide a framework that encompasses the design and evaluation of HSDPA systems and gives key insight into implementation issues in order to meet the conformance requirements.

Index Terms — Wideband code division multiple access, radio frequency, impairments, software simulation, modeling, system analysis and design, circuits, power amplifiers, mixers.

I. INTRODUCTION

In this paper, we investigate the design and simulation of an HSDPA system that includes the baseband functions as well as radio-frequency (RF) processing. It is important to eliminate over-design of components by knowing a priori the required margin. A competitive design requires that the system meets the performance metrics while keeping the implementation complexity sufficiently low. This will lead to lower cost, lower power consumption, and more competitive products. As such, the design complexity depends on the interaction and trade-offs between circuit and system implementations. The degradation in performance is caused by hardware impairments due to operating conditions, and implementation algorithms and therefore the assessment of performance relies on accurate modeling and simulation.

We define a set of conformance metrics and evaluate the design decisions against these specifications. In addition, imperfections in the implementation are considered. In particular, the hardware imperfections of the nonlinear amplifier, RF and analog transceiver, and circuit components are modeled and simulated. The degradations due to the channel conditions and impairments such as phase noise, noise figure (NF), third-order intercept (IP3), phase and gain imbalance, DC offset, etc. can also be quantified.

II. STRUCTURE OF TRANSMITTER AND RECEIVER

The baseband signal processing functions for the simulation testbench are designed and implemented using the

Visual System Simulator™ [1] design environment. The channel types, modulation, coding, spreading and framing are designed based on the specifications in [2] and therein. Each conformance test is specified in terms of the five test model (TM) configurations listed in Table I, which specifies the number of active channels for each TM.

The baseband demodulation algorithms are designed and implemented in the receiver for the channel types specified in all the TM's. The RF and circuit elements and architectures are also designed and analyzed as shown below.

TABLE I
NUMBER OF ACTIVE CHANNELS IN TEST MODELS 1-5

Channel Type	TM 1	TM 2	TM 3	TM 4	TM 5
P-CCPCH+SCH	1	1	1	1	1
Primary CPICH	1	1	1	1	1
PICH	1	1	1		1
S-CCPCH containing PCH (SF=256)	1	1	1		1
DPCH (SF=128)	16/32/64	3	16/32		30/14/6
HS-SCCH					2
HS-PDSCH (16QAM)					8/4/2002

III. CONFORMANCE TESTS

The conformance tests specified in [2] are separated into transmitter and receiver tests. Both sets of tests use the active channel configurations of the five test models as specified previously. The transmitter characterization quantifies the acceptable performance of the modulator in the presence of the non-linear power amplifier (PA), filtering, and the frequency conversion chain. The receiver characterization is a measure of the performance of the transceiver and RF processing chain, and demodulation performance. We consider the following transmitter (TX) and receiver (RX) tests:

A. Transmitter Tests

- Occupied bandwidth – percentage of the emitted signal falling in the specified channel bandwidth.
- Spectrum emission mask – out of band emissions at particular power levels and frequency offsets.

- Adjacent channel leakage power ratio (ACLR) – the ratio of the power centered on the assigned channel frequency to the power centered on an adjacent channel frequency.
- Spurious emissions – characterization of the unwanted transmitter effects such as harmonic and parasitic emissions as well as intermodulation and frequency conversion products.
- Transmit intermodulation – measure of the 3rd and 5th order intermodulation products of the nonlinear elements due to the presence of the desired signal and a WCDMA interferer at specified frequency offsets and power levels.
- Error vector magnitude (EVM) – measure of the difference between reference and measured waveforms.
- Peak code domain error (PCDE) – computed by projecting the error vector onto the code domain at a specific spreading factor. The Code Domain Error (CDE) for every code in the domain is defined as the ratio of the mean power of the projection onto that code, to the mean power of the composite reference waveform. This ratio is expressed in dB. PCDE is defined as the maximum CDE for all codes.

B. Receiver Tests

- Receiver sensitivity – the minimum received mean power at which the bit-error-ratio (BER) shall not exceed a specific value.
- Dynamic range – the ability of the receiver to handle an increase in the interference level for a specified BER and degradation in the sensitivity.
- Adjacent channel selectivity – measure of the receiver’s ability to receive a wanted signal in the presence of an adjacent channel interferer at a specified frequency offset.
- Blocking characteristics – measure of the receiver’s ability to receive a wanted signal in the presence of various unwanted interferers at a nonadjacent frequency offset.
- Intermodulation characteristics – measure of the receiver’s ability to reject third and higher order mixing products caused by two interfering signals in the band of the signal of interest.

IV. TRANSMITTER RESULTS

The system simulation for the TX tests is shown in Fig. 1. The HSDPA source is configured for each of the test models described in Table I. The device under test (DUT) is a power amplifier with the following characteristics: noise figure (NF) of 3 dB, 25 dB linear gain, and a variable input 1-dB compression point (P1dB). The 2nd and 3rd order intercept points, IP2 and IP3, are approximately IP3 + 10 dB and P1dB + 9.636 dB, respectively. This nonlinear amplifier causes distortion which is quantified through the various TX metrics such as spectral re-growth, EVM, etc. [3].

For the EVM test, the HSDPA source is configured to Test Model 1 (TM1), and the input power to the amplifier is swept from 10 dBm to 24 dBm in steps of 2 dBm. The P1dB values of 20, 25, and 30 dBm are simulated and the results are

shown in Fig. 2. The EVM is calculated in percent as a function of the output power of the amplifier. The input back-off (BO) can be calculated from this graph as the difference between P1dB and the input signal power. For example, with P1dB of 25 dBm, the upper curve data point BO levels are from 10 dB to –4 dB in steps of 2 dB.

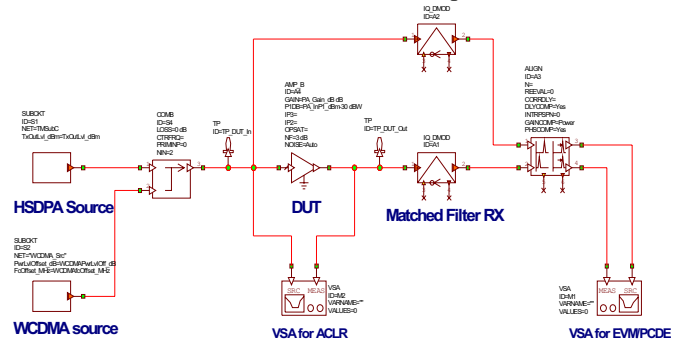


Fig. 1. Transmitter test system with interferer for intermodulation.

The EVM specifications for TM1 require that the EVM be less than 17.5%. From Fig. 2, we see that an amplifier designed with a P1dB of 20 dBm, will achieve an EVM below this threshold at about a 2.5 dB BO, while providing over 40 dBm of output power. Amplifiers designed with higher P1dB values will achieve an EVM below this threshold at lower BO levels, while providing larger output power. For 25 dBm P1dB, the EVM threshold is achieved at about 2 dB BO. As such, a design tradeoff can be made with respect to amplifier efficiency and complexity.

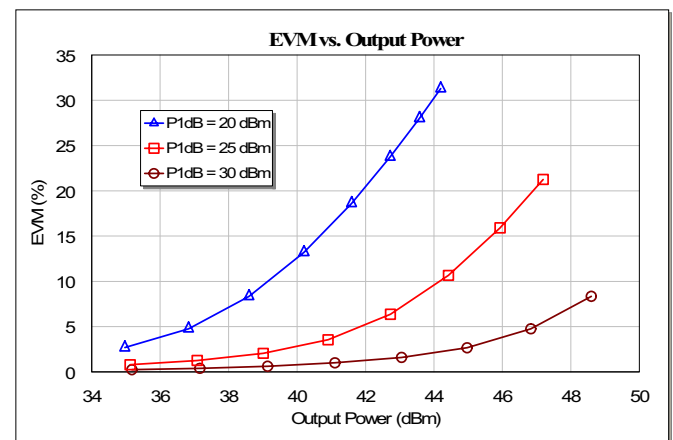


Fig. 2. EVM vs. output power with three P1dB values.

The ACLR test is performed with TM1 and input powers of 10 dBm to 20 dBm. The power is computed over a 3.84 MHz bandwidth on-channel and at 5 MHz and 10 MHz offset from the carrier frequency. The RRC filter alpha parameter is 0.22. This test requires that the ACLR be less than –45 dB and –50 dB at 5 and 10 MHz offsets, respectively. Table II lists the results for a P1dB of 25 dBm. The amplifier with P1dB of 20 dBm did not satisfy the ACLR requirements at 5 MHz offset.

TABLE II
TX MEASUREMENT RESULTS

Input Power (dBm)	ACLR (dB)		Occupied BW (%)	3rd-order Intermodulation (dB)		5th-order Intermodulation (dB)		PCDE (dB)
	@5MHz	@10MHz		@10MHz	@-5MHz	@15MHz	@-10MHz	
10.0	-51.8	-81.0	99.999	-78.8	-51.0	-84.9	-79.0	-65.6
12.0	-47.7	-80.8	99.998	-76.7	-47.0	-84.9	-77.3	-61.5
14.0	-43.6	-79.4	99.995	-72.9	-42.9	-84.4	-73.9	-57.2
16.0	-38.7	-72.7	99.985	-66.9	-37.9	-82.4	-67.7	-52.5
18.0	-33.3	-63.2	99.956	-61.1	-32.5	-76.0	-61.4	-47.7
20.0	-28.9	-56.8	99.869	-55.0	-28.2	-69.6	-55.1	-43.3

This table also lists the occupied bandwidth percentage for the same test configuration as the ACLR measurement over a 5 MHz bandwidth. The conformance requirement for the percentage occupied bandwidth is that it should be greater than 95%. This is shown in Table II to be easily met.

Table II also displays the results of the transmit intermodulation test. This test includes the addition of a WCDMA interfering source with the wanted HSDPA source. The WCDMA interferer has a power level 30 dB lower than the swept input power of the HSDPA signal and an offset of +5 MHz. The ACLR is measured at +10 MHz and -5 MHz offset for the 3rd order, and at +15 MHz and -10 MHz for the 5th order. The requirement is less than -45 dB and -50 dB for 3rd and 5th order intermodulation ratios, respectively.

The PCDE results are computed using TM3 and also displayed in Table II with a P1dB of 25 dBm. The specification requires the PCDE to be less than -33 dB.

generates an uplink signal containing a 12.2 kbps data channel and the appropriate control channels. The device under test (DUT) consists of a front-end filter, a low-noise amplifier (LNA) followed by a band-pass filter, a mixer that performs direct-conversion to DC and a low-pass filter. These components contain real-world hardware impairments, such as thermal and phase noise, and linear and nonlinear distortion. The base station (BS) receiver performs data demodulation and decoding, and calculates the bit-error-rate (BER) as a measure of performance.

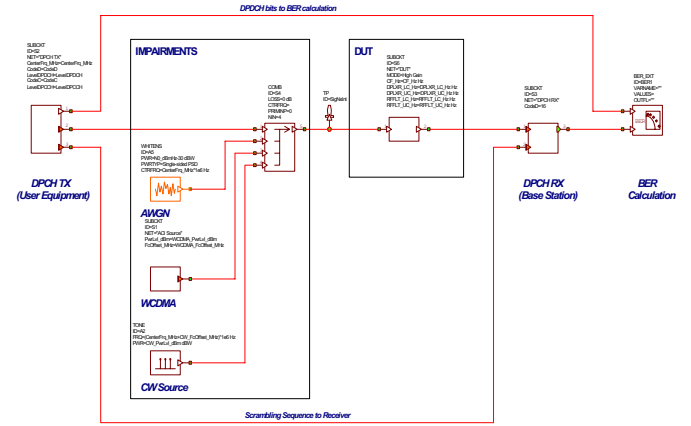


Fig. 4. Receiver test system with BER calculation.

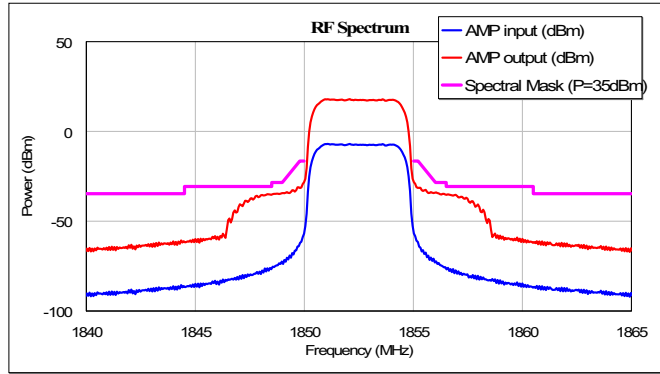


Fig. 3. Input and output spectrum and TX mask.

The spectrum emission mask is shown in Fig. 3 and the resulting spectrum before and after amplification is displayed. The spectral re-growth and spurious emissions need to be below the mask levels. In this figure, the input power is 10 dBm and the P1dB is 25 dBm.

V. RECEIVER RESULTS

The system simulation for the RX tests is shown in Fig. 4. The HSDPA source is a mobile station transmitter which

generates an uplink signal containing a 12.2 kbps data channel and the appropriate control channels. The device under test (DUT) consists of a front-end filter, a low-noise amplifier (LNA) followed by a band-pass filter, a mixer that performs direct-conversion to DC and a low-pass filter. These components contain real-world hardware impairments, such as thermal and phase noise, and linear and nonlinear distortion. The base station (BS) receiver performs data demodulation and decoding, and calculates the bit-error-rate (BER) as a measure of performance.

An additive white Gaussian noise source is used for performing the sensitivity level test. In this case, the noise source simulates thermal noise with a flat power spectral density at a level of -174 dBm/Hz. The power level of the HSDPA signal source is swept around the nominal conformance level and the BER is calculated. Reference [2] specifies three types of BS receivers: Wide Area BS, Medium Range BS and Local Area BS. Each of them is required to achieve a BER of 0.001 at signal levels of -121 dBm, -111 dBm, and -107 dBm, respectively.

A number of design parameters in the DUT can be adjusted by evaluating their effect in the BER performance. This simulation framework allows the user to modify hardware design parameters, such as the mixer IP2, which is important in direct conversion architectures with interfering signals, or the amplifier compression point, and use the BER as a real-

time performance metric. This avoids the need for relying strictly on simpler measurements, such as EVM, therefore leading to over-designing of the hardware components.

A WCDMA source and a continuous-wave (CW) tone are employed for evaluating the blocking characteristics of the receiver. For the Wide Area BS, the CW tone and WCDMA source are set at the same power level of -48 dBm, while their frequency offsets are 10 MHz and 20 MHz, respectively. The nominal power level of the HSDPA signal remains the same. The parameters of the filters used in the DUT can be adjusted so that the receiver achieves the required BER performance.

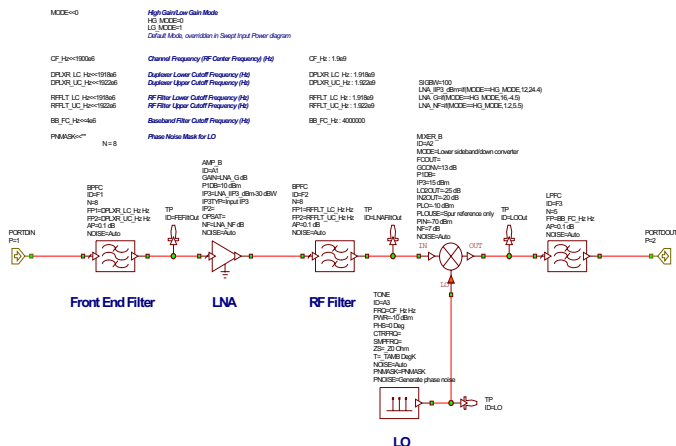


Fig. 5. Direct downconversion receiver chain (DUT).

A diagram of the DUT is shown in Fig. 5. The signals at the input of the DUT, output of the front-end filter, and output of the band-pass filter after the LNA are shown in Fig. 6. The wanted signal is at -115 dBm with a center frequency 1920 MHz.

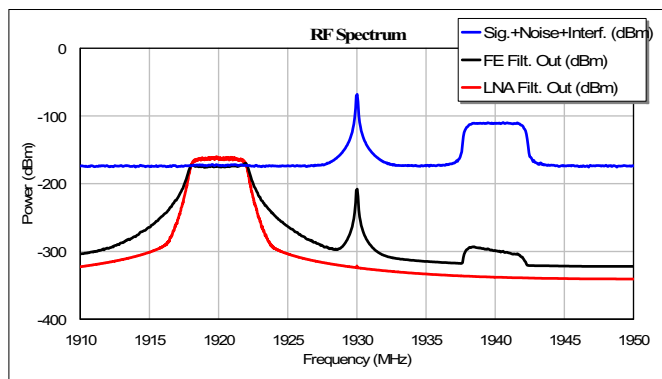


Fig. 6. RX spectrum at input and after two stages of filtering.

The LNA gain is 16 dB with a NF of 1.2 dB, IP3 of 12 dBm and P1dB of 10 dBm. The mixer has a conversion gain of 13 dB, IP3 of 15 dBm, and low isolation. The filter parameters are chosen such that the interfering signals are suppressed to levels very close to the noise floor employing 8th order Chebyshev designs.

A sample of the BER results is shown in Fig. 7. The reference BER curve was calculated without the DUT and no interfering signals, which represents the BER performance without any degradation due to the RF hardware implementation. Results of the RX sensitivity and blocker characteristics tests are also shown. The current settings of the DUT cause a performance degradation of about 2.5 dB. However, this performance still provides an implementation margin of about 7 dB, since, for Wide Area BS, a BER of 0.001 should be achieved at a signal level of -121 dBm.

The framework described in this paper allows trade-offs of hardware design parameters by monitoring their effects using the RX tests of [2]. Due to space limitations, only a few of these tests were presented in this paper.

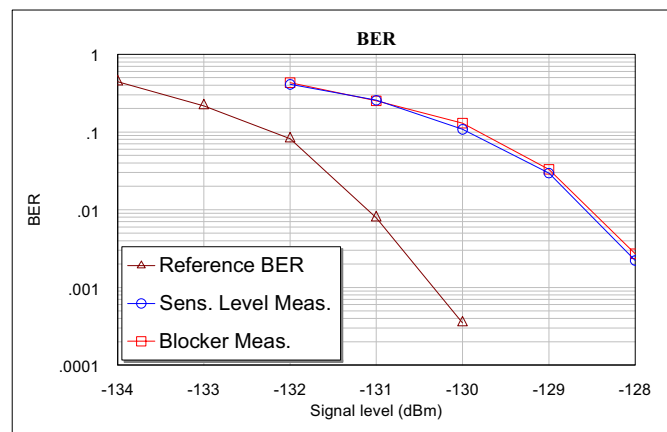


Fig. 7. BER results for RX sensitivity and blocker characteristics.

VI. CONCLUSION

We have provided a framework for the design, modeling, and evaluation of the performance of an HSDPA system and quantified the effects of system and circuit interactions. This will allow designers of such systems to make informed decisions and gives key insight into implementation issues in order to meet the conformance requirements.

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