Technical Article

3GPP Radio Prototyping Using Radio420X

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3GPP Radio Prototyping Using Radio420X

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Abstract

This application note addresses 3GPP radio design and prototyping when using the Nutaq Radio420X FPGA mezzanine card (FMC). It discusses the most critical radio requirements as they relate to 3GPP radio conformance testing, namely TS 51.021 (GSM) and TS 36.141 (LET). Being similar to some extent to LTE, we invite the reader to apply the same methods and analysis to WCDMA. The main focus is on the GSM DCS1800 pico base station (BTS) and the LTE local area and home eNB. The scope is limited to FDD in UMTS bands 1, 2, 3 and 4, with a 5 MHz bandwidth for LTE enhanced node B (eNB).

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1 Introduction

RF transmitters must be designed to generate a clean signal within the assigned spectrum while keeping unwanted spurious products within allowable levels. Likewise, receivers must reliably demodulate the wanted weak signal while also rejecting interference from neighbouring channels. Performance requirements for these RF characteristics aim to ensure that equipment authorized to operate on GSM or LTE carriers meets certain minimum standards [1]-[2].

This document focuses on the frequency bands and arrangements for FDD as shown in Table 1-1. Other frequency bands and arrangements can be found in TS 36.141 [2].

Table 1-1 **GSM and LTE (UMTS) frequency bands for FDD**

Band Number	Uplink (MHz)	Downlink (MHz)	Band Gap (MHz)	Duplex Separation (MHz)	GSM Usage	LTE Usage	Comment
1	1920–1990	2110–2170	130	190	N	Y	
2	1850–1910	1930–1990	20	80	Y	Y	PCS1900
3	1710–1785	1850–1880	20	95	Y	Y	DCS1800
4	1710–1755	2110–2155	355	400	N	Y	

The design of the LTE physical layer (PHY) is heavily influenced by requirements for a high peak transmission rate (100 Mbps downlink/50 Mbps uplink), multiple channel bandwidths (1.25 to 20 MHz), and spectral efficiency. To fulfill these requirements, orthogonal frequency division multiplexing (OFDM) was selected as the basis for the physical (PHY) layer. The use of OFDM and multiple-input/multiple-output (MIMO), two key technologies, significantly differentiate LTE from other 3G systems such as WCDMA. LTE adopts different modes of operation (FDD/TDD) and different downlink and uplink access technologies (OFDMA, SC-FDMA). GSM, on the other hand, uses GMSK modulation in both uplink and downlink directions. Time division multiple access (TDMA) was adopted in GSM as a multiple access scheme wherein one time frame can support up to eight users.

2 Radio420X capabilities and RF performance

The Radio420X FPGA mezzanine card (FMC) is a powerful multi-mode software-defined radio (SDR) RF transceiver module. The Radio420X is designed around the state-of-the-art, multi-standard, multi-band Lime Microsystems LMS6002D RF transceiver IC, which supports broadband coverage, as well as TDD and FDD full duplex modes of operation [3].

The LMS6002D RF transceiver IC's bandwidth (1.5–28 MHz) is selectable on-the-fly, suitable for a large number of narrowband and broadband applications, and offers excellent channel selectivity.

Figure 2-1 shows the Radio420X FMC with its shield removed.

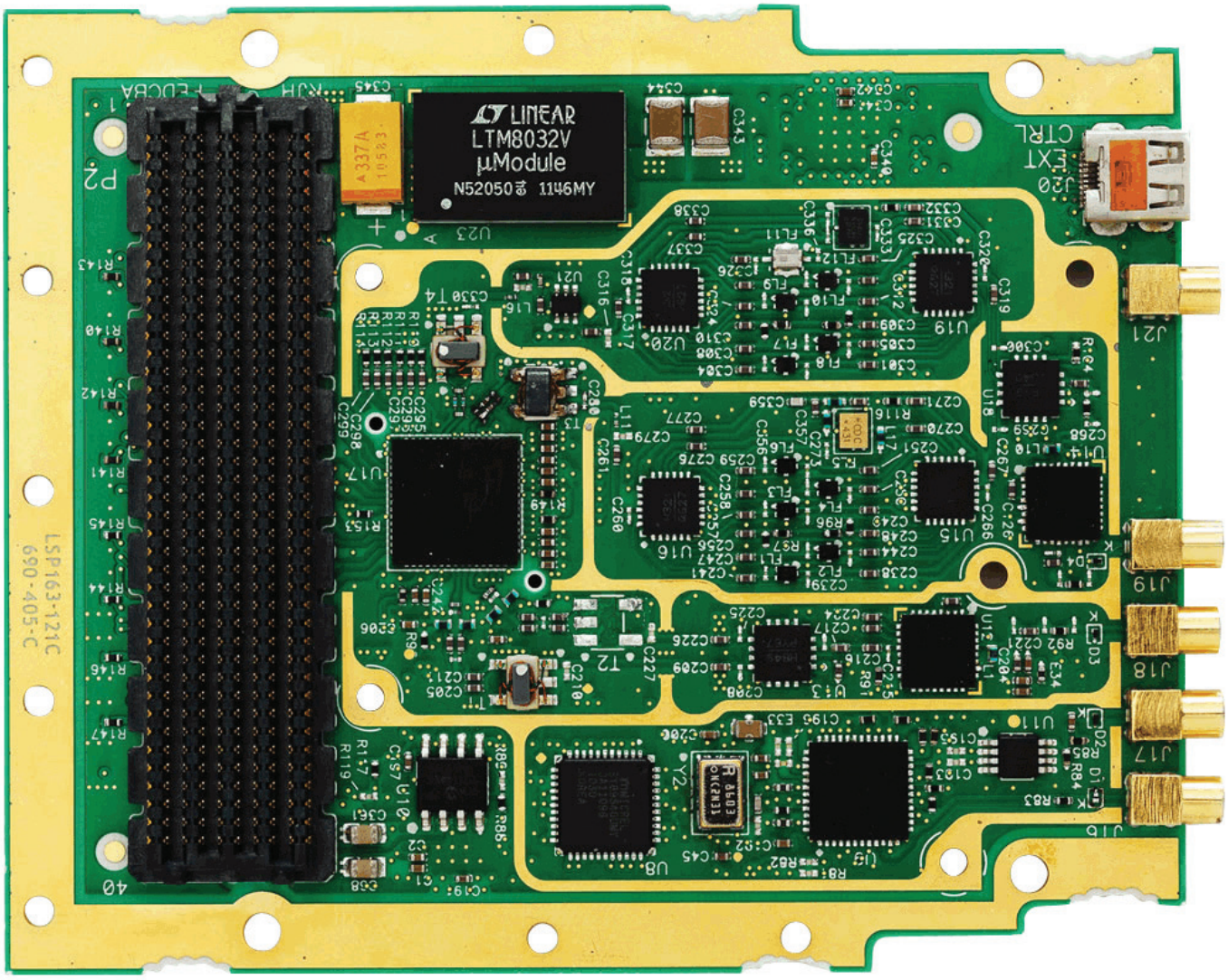


Figure 2-1 FMC Radio420X board with shield removed

Figure 2-2 shows the Radio420X's functional block diagram.

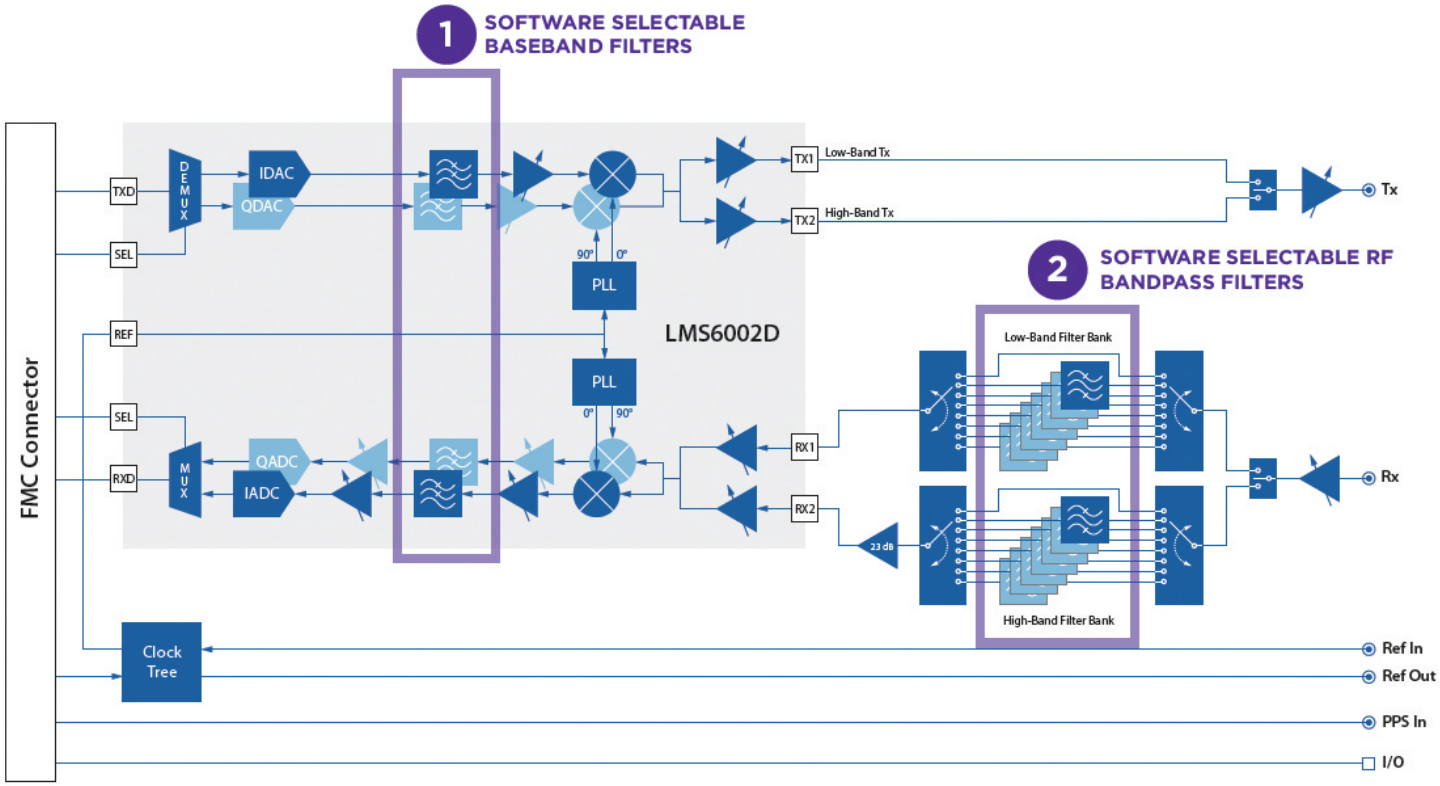
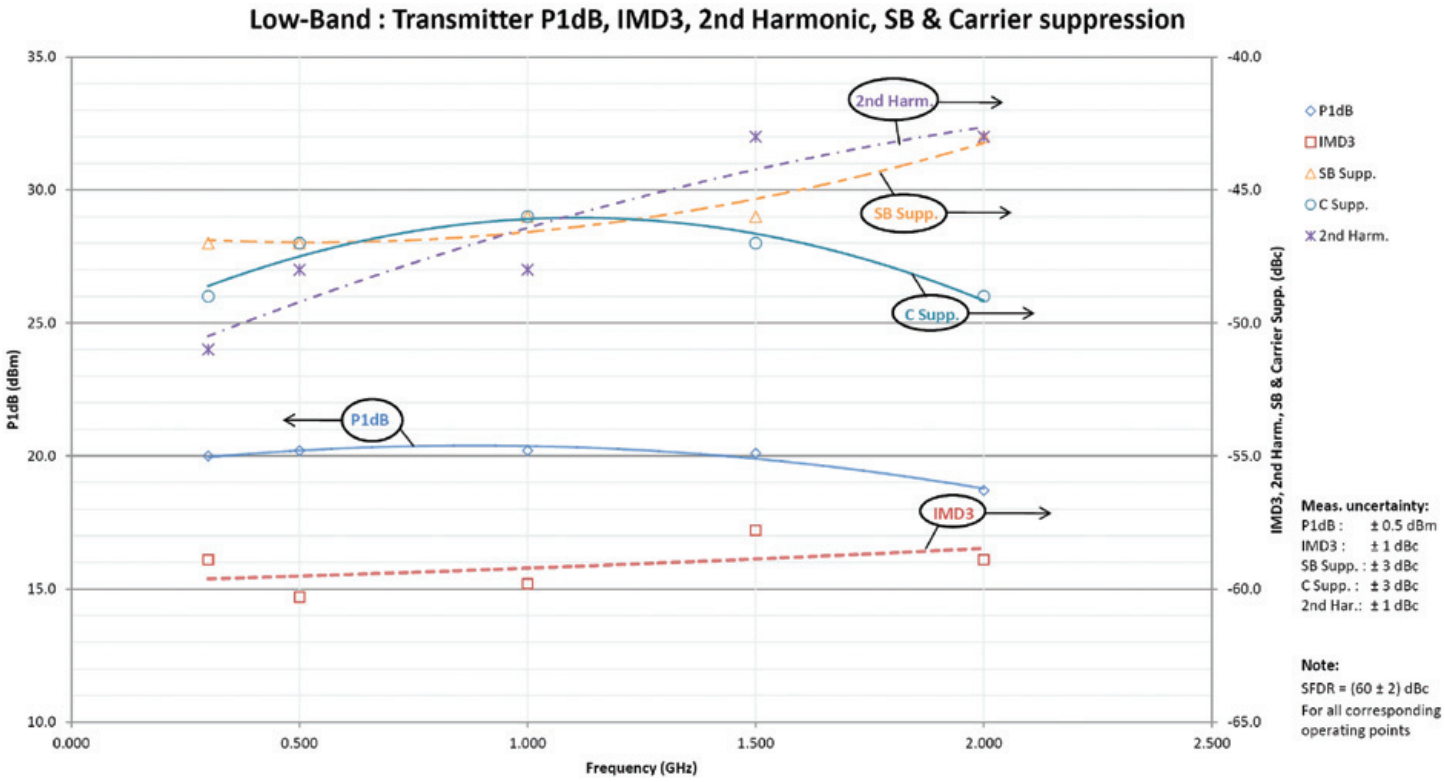


Figure 2-2 Functional block diagram

Supporting multiple references and synchronization modes, the Radio420X is the right choice for applications like multi-mode software-defined radio (SDR), advanced telecommunication systems (MIMO systems, cognitive radios, WiMAX, white space, Wi-Fi, GSM, WCDMA), and signal intelligence (SIGINT). The Radio420X complies with VITA 57.1, a widely used standard in the digital signal processing industry, making it easier for developers to integrate FPGAs into embedded system designs.
The Radio420X is completely integrated with the Nutaq uTCA Perseus AMCs, but it can just as easily be used with other FMC carriers. It is compatible with both low pin-count (one RF transceiver) and high pin-count (two RF transceivers) FMC interfaces.

The Radio420X's TX and RX analog paths are designed to offer the best versatility-to-performance ratio, addressing the high demands of multi-mode RF applications. At the transmitter end, a software-selectable RF switch enables the LMS6002D's low-band TX1 output or the high-band TX2 output. This switch is followed by a 6-bit, 4 GHz broadband variable gain amplifier where the gain is adjustable from -13.5 to 18 dB (in addition to the LMS6002D's TX VGAs), yielding a maximum output power of 20 dBm.

Figure 2-3 shows the TX RF performances in terms of output compression point, third-order intermodulation products, RF harmonics level, unwanted sideband rejection, and local oscillator leakage level. Using the low band TX path, one would expect +20 dBm OP1dB, better than 40 dB and 45 dBc for harmonic filtering and LO leakage, and unwanted sideband suppression (using auto-calibration routines) while keeping intermodulation products around -60 dBc.



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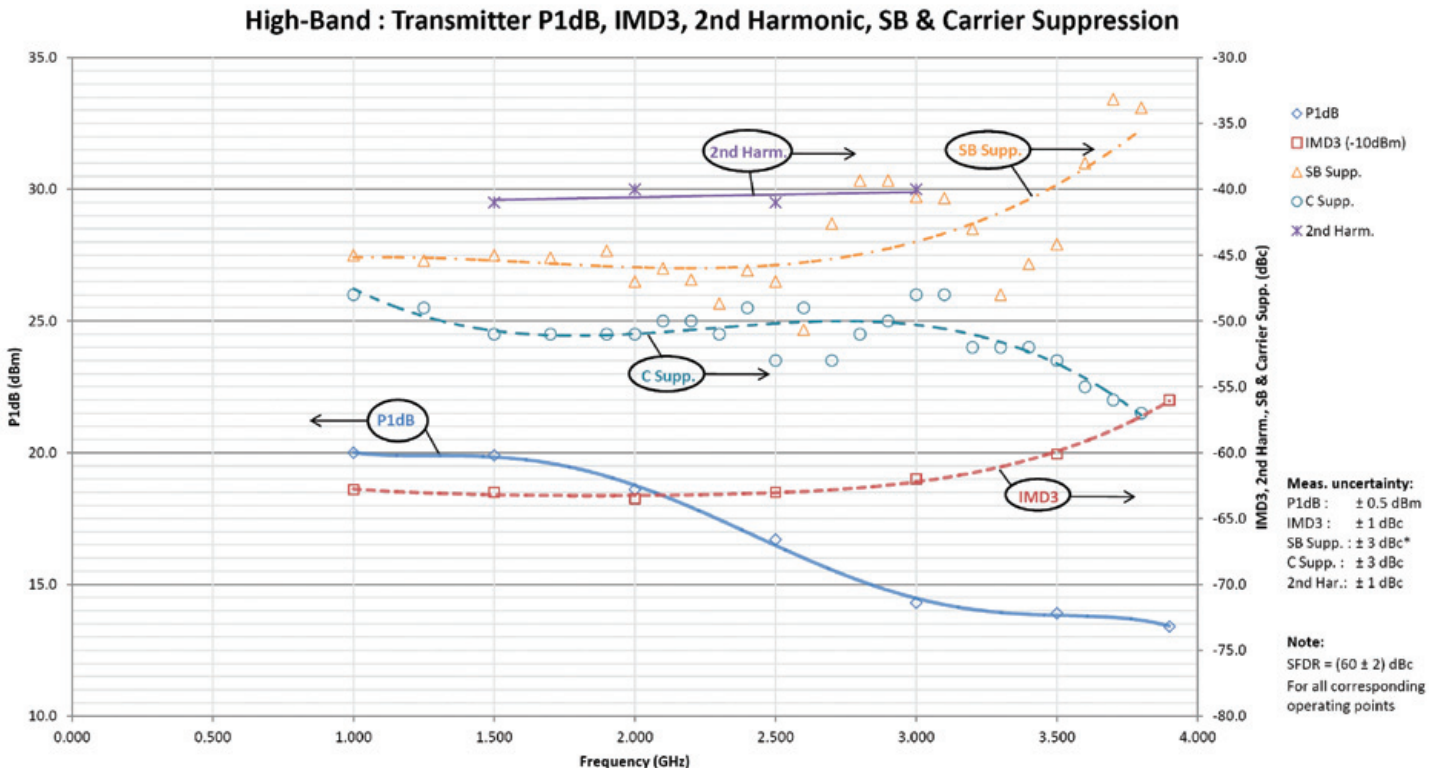

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Figure 2-3 **Radio420X transmitter performance:**
a) low band from 300 MHz to 2000 MHz and b) high band from 1500 MHz to 3800 MHz

At the receiver end, a similar 6-bit, 4 GHz broadband variable gain amplifier is present on top of the integrated LMS6002D's RX VGAs. The amplifier is followed by a software-selectable RF switch that enables the LMS6002D's low-band RX1 path or the high-band RX2 path. Each RX path has eight software-selectable filter banks.

Figure 2-4 describes the filter banks on each path.

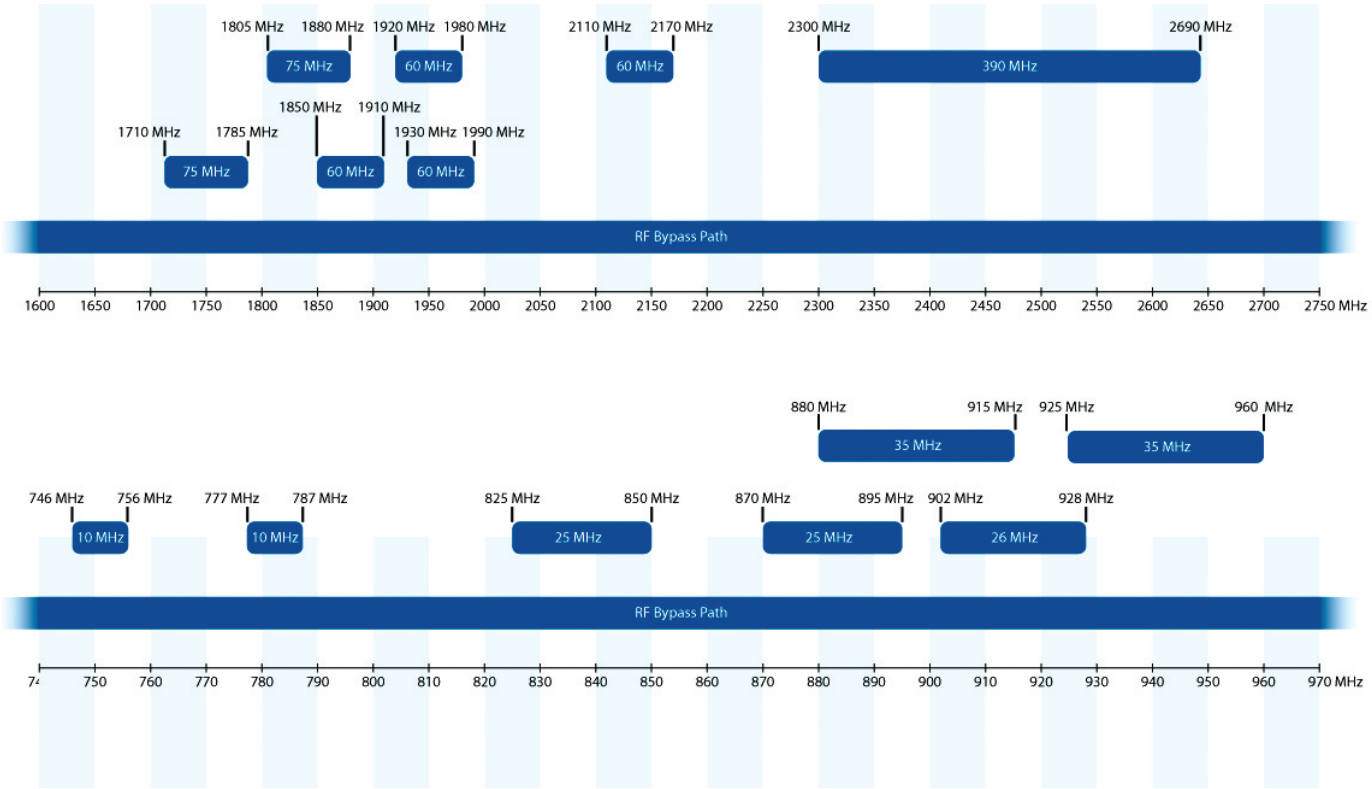
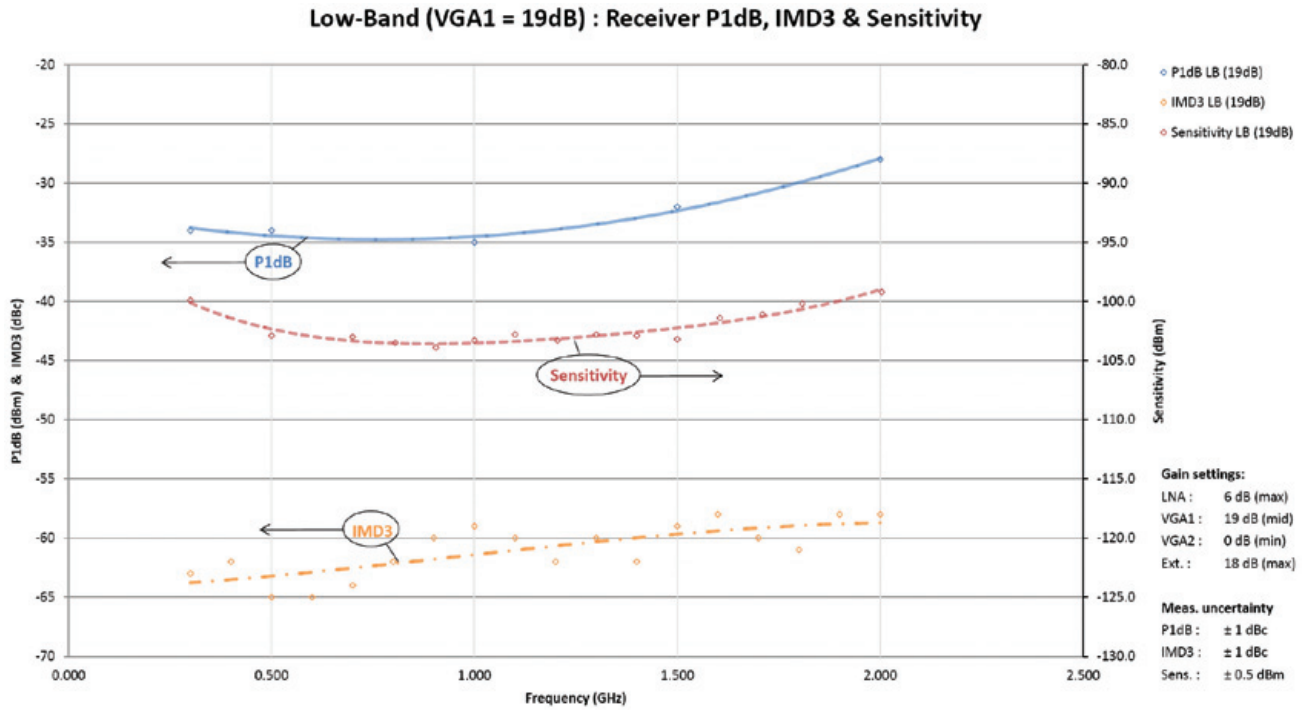


Figure 2-4 **FMC Radio420X RX filter banks**

The receiver filter bank uses band-pass SAW filters that provide greater than 40 dB of out-of-band-blocker filtering and transmitter signal leakage rejection when operating with the right duplexing separation. The filter bank supports most relevant 3GPP and IEEE standard radios.

Figure 2-5 shows typical RX RF performance curves. These consist of the input compression point, intermodulation products, and sensitivity. For the UMTS bands of interests (see Table 1-1), using the same minimum gain settings, one would expect a typical noise figure, 3rd-order intermodulation products, and input compression point of 10 dB, -58 dBc and -28 dBm, respectively.



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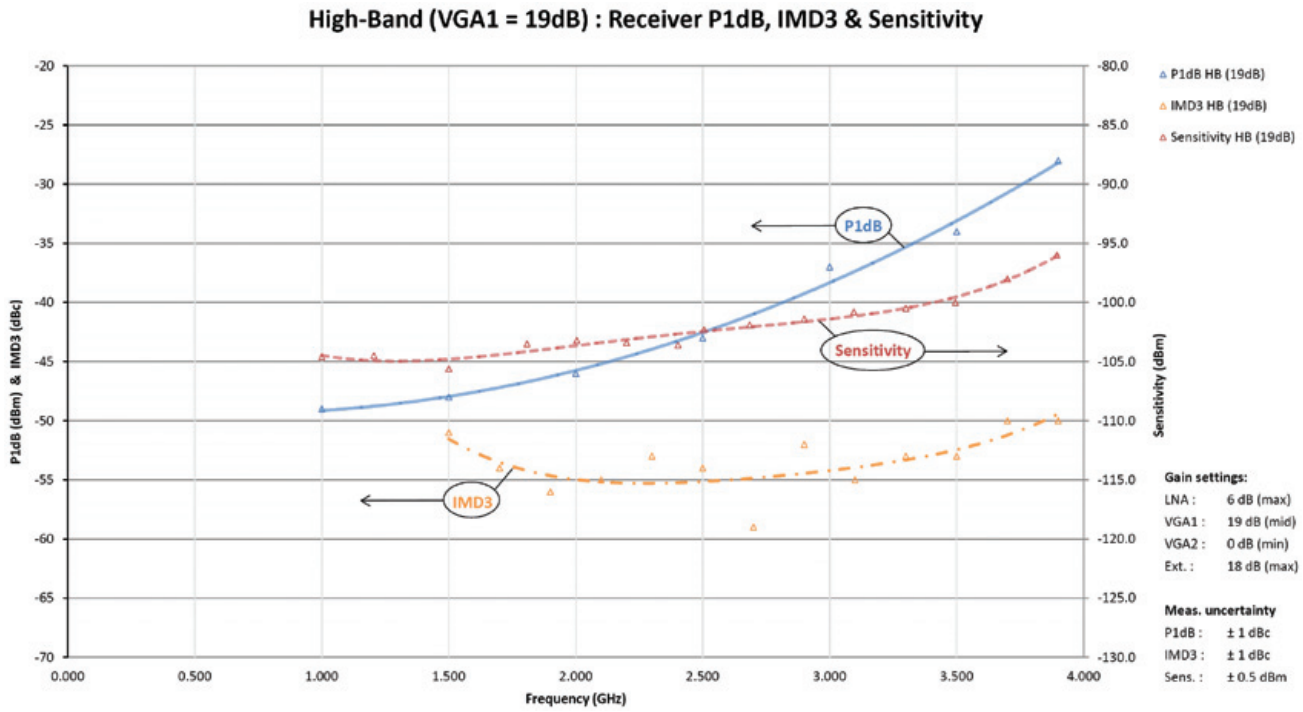

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Figure 2-5 **Radio420X receiver performance:**
a) Low band from 300 MHz to 2000 MHz and b) high band from 1500 MHz to 3800 MHz

In the subsequent sections of this document, we will demonstrate the Radio420X's suitability for 3GPP radio design and prototyping by linking its RF performance values to frequently used 3GPP metrics, including but not limited to EVM and ACPR for the transmitter, and sensitivity and intermodulation attenuation for the receiver.

3 Transmitter RF requirements

This section discusses the implications of GSM and LTE RF performance specifications when designing transmitters. Transmitters must meet two sets of requirements: those relating to the quality of the intended transmissions, and those addressing the level of allowable unwanted emissions.

3.1 Modulation accuracy: frequency error, phase error and error vector magnitude

For GSM, GMSK modulation accuracy is measured in terms of phase error. For the PICO BTS class, the phase error shall not exceed 5 degrees RMS and 20 degrees peak while maintaining the mean frequency error across the burst below 0.1 parts per million (ppm) [1]. The latter requirement is met with the Radio420X's high stability VCTCXO. Phase error is used to verify the correct implementation of the GMSK modulator and pulse shaping filtering within the above specified limits under normal and extreme test conditions and when subjected to vibration. Analog baseband IQ unbalance and local oscillator (LO) IQ arms mismatch will also affect phase error. These RF impairments at the antenna port can be resolved using an appropriate calibration routine (already supported in the Radio420X's calibration software). Care shall also be taken in PCB layout design to ensure no RF return signal is fed back from the antenna to the final amplifier stages. Fortunately, shielding can help for designs with high-output power levels.

For LTE, error vector magnitude (EVM) is used. EVM is a measure of the difference between the ideal symbols and the measured symbols after equalization. The equaliser parameters are estimated as defined in Annex F of TS 36.141 [2]. The EVM result is defined as the square root of the ratio of the mean error vector power to the mean reference power expressed as a percentage. Depending on the modulation and coding scheme, the purpose of testing is to verify that the EVM is within the limit specified by the minimum requirement, as shown in Table 3-1.

Table 3-1 **Required EVM for PDSCH**

Modulation scheme for PDSCH	Required EVM (%)
QPSK	18.5
16QAM	13.5
64QAM	9

When used in conjunction with other parameters, EVM captures the effect of many different signal distortions [4]. It can help pin-point transmit impairments related to:

- Phase noise and frequency error
- IQ imbalance (gain and phase mismatch can create LO leakage and unwanted sideband components)
- Signal compression effects and nonlinearities
- Spurious components

We will relate EVM to the above signal impairments and provide quantitative measurements on the Radio420X to help assess the EVM calculation process.

As far as phase noise is concerned, LO phase noise consists of random fluctuations around its center frequency. One common definition is the single sideband phase noise density $L(f)$ in dBc/Hz for a given frequency offset f or aggregately in terms of RMS phase noise θ_{rms} in radian over the information bandwidth. Phase noise affects modulation accuracy and contributes to EVM. The effect appears visually as a circular distortion of the signal points near the center of the constellation.

For example, Let's look at the Radio420X's LO phase noise contribution to EVM. The Radio420X's LO phase noise at 2GHz is typically -52dBc/Hz, -70dBc/Hz, -84dBc/Hz, -88dBc/Hz, -94dBc/Hz, -120dBc/Hz and -136dBc/Hz at 10Hz, 100Hz, 1kHz, 100kHz, 100kHz 1MHz and 10MHz offsets, respectively. The calculated RMS phase noise of 0.96o will translate to 1.7% (-35.4 dB) EVM. The following formula (assuming a high SNR and using 2-order Tailor series expansion and zero-mean Gaussian distribution for the phase noise) can be used:

$$EVM_{rms} \approx \sqrt{\frac{1}{SNR} + \sigma^2},$$

where σ is the RMS LO phase noise.

On the other hand, DC offsets, gain and phase mismatches in in-phase and quadrature IQ signal paths will directly affect modulation accuracy. These impairments can be seen as LO leakage and unwanted sideband rejection performance. As far as the constellation is concerned while particularly viewing BPSK pilot symbols, an IQ gain mismatch would result in pilot symbols spread mostly along the I-axis, while a phase mismatch would result in the pilot symbols spread along the Q-axis. Most transceivers and vector modulators specify these impairments as LO leakage and single sideband rejection in dB. A closed form relationship relating to EVM can be used to assess their contributions as follow

$$EVM_{CL} = 10^{A_{CL}/20} \text{ and } EVM_{SSB} = 10^{A_{SSB}/20}$$

where A_{CL} and A_{SSB} are the carrier leakage and single sideband rejections (SSB) in dB. For reference, the typical carrier leakage and sideband suppression of the Radio420X is -45 dB. Both leakages will contribute to about -45 dB of EVM each. One should also notice the dB to dB relationship between EVM, carrier leakage, and unwanted SSB suppressions in high SNR cases.

The last point to discuss is the impact of nonlinearities as represented by third order intermodulation components. These tend to be higher when the transmitter operates near a 1 dB compression point. Nevertheless, the rule of thumb, which would also be dictated by the adjacent channel power ratio (ACPR) specification, is to operate at a backoff equivalent to the OFDM peak to average ratio (PAR). While doing so, the EVM will not only depend on the intermodulation product level but will also involve the input and the output of the interfering tones levels P_{RFIN} and P_{RFO}. The EVM can be approximated as:

$$EVM_{IM3} = 10^{-(2OIP3+P_{RFO}-3\cdot P_{RFIN})/20}$$

with OIP3 being the output third order intercept point. For reference, the 1 dB compression point and OIP3 for the Radio420X output are, respectively, +20 dBm and +30 dBm for low band frequencies around 2 GHz. As shown in Table 3-2, the aggregate EVM for the Radio420X is dominated by LO phase noise.

Table 3-2 **Radio420X EVM**

Parameter	Value
Frequency band	300 MHz to 3800 GHz
Carrier leakage suppression at 2GHz	-45 dBc
Side band rejection	-45 dBc
OIP3	+30 dBm
P_{RFO}	0 dBm
RMS LO phase noise at 2 GHz	0.96°
Calculated EVM	1.73% or -35.2 dB

To conclude, the reader should note the following assumptions and limitations regarding the scope and accuracy of our analysis:

1. It makes assumptions on noise distribution and high SNR signals. It does, however, provide a good understanding of EVM budget analysis in relationship to different radio transmitter impairments.
2. It does not account for inter-carrier interference that an IQ gain and phase unbalance would create on a mirror subchannel, nor for the LO phase noise and spurious components created on the adjacent subchannels.
3. It does not account for the contribution of in-band spurious products that would typically be caused by reference clock harmonics (due to finite PCB material substrate isolation).

Meeting the LTE specification on frequency error for local area and home eNB requires less stringent specifications, +/-(0.1ppm +12Hz) and +/-(0.25ppm +12Hz) respectively.

3.2 Adjacent channel power

For GSM (GMSK), the modulation, wideband noise and power level switching spectra can produce significant interference in the relevant TX and adjacent bands. The requirements for adjacent channel emissions are tested by two separate tests that measure different sources of emission:

- Continuous modulation spectrum and wideband noise
- Switching transients' spectrum

We will focus on the first item, which is mostly affected by the transmitter VCO and amplifier stages. The modulation spectrum puts stringent limitation on VCO phase noise. For the DCS1800 pico BTS class, the maximum limits are stated in Table 3-3 and compared to the Radio420X's measured phase noise at 2 GHz. This demonstrates that the Radio420X can meet continuous modulation spectrum and wideband noise requirements.

Table 3-3 **PCS1800 pico's modulation spectrum and minimum VCO requirement**

Frequency offset in kHz	Maximum limit per TS 51.021 (in dBc/BW)	Maximum VCO phase noise in dBc/Hz	Radio420X measured phase noise @2GHz
+/- 200	-30dBc/30kHz	-75 =-30dBc/Hz -10 Log (30Khz)	-96
+/- 250	-33dBc/30kHz	-78	-100
+/- 400	-60dBc/30kHz	-105	-108
+/- 600–1200	-60dBc/30kHz	-105	-115
+/- 1200–1800	-63dBc/30kHz	-108	-120
+/- 1800–6000	-76dBc/100kHz	-126	-130
>+/- 6000	-80dBc/100kHz	-130	-136

The density of PCBs with small form factors (e.g. FMC) is a concern in radio design, as many sources of noise and spurious products may sneak out with the RF signal. The power supply noise (mainly DC-DC converter switching noise), for instance, can appear along with the RF signal close to the carrier (depending on the power supply switching frequency). Hopefully, these can be contained within the number of allowed exceptions.

In LTE, the adjacent channel leakage power ratio (ACLR) is defined as the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency. The requirements apply outside of the RF bandwidth edges, regardless of the type of transmitter being considered (single carrier or multi-carrier). The minimum requirement for Category B eNB (which includes local area and home eNBs) in paired bands is 44.2 dB or -15 dBm/MHz.

It is interesting to relate ACPR to the 3rd order intermodulation distortion (IMD3) measured on the Radio402X. The increase in ACLR is mainly due to increased adjacent channel occupancy by 3rd and 5th order intermodulation components [5]. ACLR has been related to IMD3[5], where an ACLR for *n* subcarrriers is calculated using two-tone IMD3 and a correction factor:

with

$$\mathrm{ACLR_n = IMD3 + C_n}$$

No of subcarriers n	1	2	3	4	9
Correction factor C_n in dB	+3	+9	+11	+12	+13

For a larger number of subcarrriers (as with LTE), a set of closed form formulas are presented in [5]. [5] relates ACPR to two-tone intermodulation ratio IMR_2 which, in turn, is linked to third order intercept point IP3 and the total output power P_{OT} :

$$\mathrm{IMR_2 = 2(IP3 - P_{OT}) + 6}$$

Following the established theory in [6-references 1 and 2 therein] the formula for n-tone ACPR is related to IMR_2 as follows:

$$\mathrm{ACPR = IMR_2 + 10log}\left(\frac{\mathrm{n^3}}{\mathrm{16N + 4M}}\right)$$

with N = $\frac{2n^3-3n^2-2n}{24}$ and M = $\frac{n^2}{4}$

for n being an integer multiple of 2.

Asymptotically ACPR will get close to IMR_2 when the number of subcarriers is high. This approximation can be applied for 20 MHz LTE signals with 2048 subcarriers, for instance.

For reference, the measured 0 dBm tow-tone IMR_2 for the Radio420X is about -58 dBc at 2 GHz. This suggests that the expected ACPR is IMR_2 with a -24.09 dBm output power per tone in case of a 5 MHz LTE signal bandwidth. One would also expect this ACLR level given that the Radio420X exhibits a typical P1dB of +20 dBm.

Over all, the Radio420X is suitable for LTE radio design and prototyping at more than +5 dBm of total average output power. When coupled with off-the-shelf pre-driver evaluation boards like the SKY77xxx, one can expect a clear LTE signal at +15 dBm (with more than 12dB back off) for femtocell applications. GMSK modulation can operate near compression using less than 3dB backoff, however, so that one would expect +17 dBm output power at the antenna connector.

3.3 Out-of-band spurious emissions

Spurious emissions in the Radio420X are mostly related to reference clock harmonics and main RF signal harmonics. The clock related spurious products are typically measured at -50dBm/100kHz while the main signal second harmonic level is at -42 dBc. Operating the Radio420X at +10 dBm will keep these spurious products below the recommended FCC limits of -30 dBm (above 1 GHz).

On the other hand, protecting the BTS receiver requires that spurious emission limitations be set at -88 dBm in a 100 kHz measurement bandwidth. This translates into a required VCO phase noise of -138dBm/Hz. With appropriate TX-RX antenna separation (a few centimeters), this criteria can easily be met.

4 Receiver RF requirements

The receiver must reliably demodulate the wanted weak signal, while also rejecting interference from neighbouring channels. This is addressed by the following requirements: reference sensitivity level, adjacent channel selectivity, receiver intermodulation, and blocking characteristics.

4.1 Reference sensitivity level

GSM defines the static reference sensitivity of the receiver as the level of signal at the receiver input with a standard test signal at which the receiver will produce, after demodulation and channel decoding data with a frame erasure ratio (FER), a residual bit error ratio (RBER), bit error ratio (BER), or block error ratio (BLER) better than or equal to that specified for a specific logical channel type under static propagation conditions. For the case of the TCH/FS logical channel, a DCS1800 pico BTS needs to meet the minimum specifications shown in Table 4-1 with a GMSK signal at -95 dBm [1].

For LTE, the reference sensitivity power level is the minimum mean power received at the antenna connector at which a throughput requirement shall be met for a specified reference measurement channel. To meet LTE requirements, a throughput of at least 95% of the maximum throughput shall be achieved with the following sensitivity level for a 5-MHz channel bandwidth. In Table 4-1, fixed reference channels A1-3 from [2] are used.

Table 4-1 **LTE eNB reference sensitivity level**

BTS class	Reference sensitivity level in dBm	Limits
DCS1800 pico BTS (GSM)	-95	FER <0.10 α % Class Ib RBER < 0.40/α % Class II RBER 2.0 % α may be between 1 and 1.6
Local area eNB (LTE)	-92.8	Throughput greater than or equal to 95% of the maximum throughput
Home eNB (LTE)	-92.8	Throughput greater than or equal to 95% of the maximum throughput

The typical Radio420X noise figure is 10 dB, which meets the DCS1800 reference sensitivity requirement assuming a required SNR of 6 dB. For an LTE eNB with QPSK 1/3 modulation and coding scheme (MCS) and a 4.0dB-required SNR (including a 2 dB implementation margin) a front-end NF of less than 10.2 dB is required.

4.2 Adjacent channel selectivity

GSM addresses adjacent channel selectivity in the scope of reference interference level. The reference interference level is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal at the same carrier frequency (co-channel interference) or at any adjacent carrier frequencies (adjacent channel interference).

For the DCS1800 pico BTS, the wanted signal is set at -75 dBm for co-channel and +/-200 kHz interferer cases and at -71 dBm in case of a strong +/-400 interferer. Table 4-2 states the carrier to interferer ratio along with the fading profile. In all scenarios, the wanted signal will undergo a TI5 fading profile.

Table 4-2 **Co-channel and adjacent channel interference rejections for TCH/FS**

Interferer offset	Carrier to interferer ratio	Fading profile for interferer
0 kHz	13 dB	TI5
200 kHz	-5 dB	TI5
400 kHz	-37 dB	Static

For the TCH/FS logical channel, the pass/fail criteria is based on the following limits with α that may vary between 1 and 1.6:

- FER < 0.10 α %
- Class Ib RBER < 0.40/α %
- Class II RBER 2.0 %

The major contributor to a co-channel interferer is the demodulator performance. The digital baseband filter needs to be carefully designed in order to negate the effect of the 200 kHz interferer. The 400 kHz interferer, however, puts stringent requirements on LNA linearity, analog baseband filters, ADC headroom, and digital filters. For the DCS1800 pico BTS, the -/+400 kHz interferer's absolute level is -34 dBm.

A similar test is defined for the LTE home and local area eNB. Figure 4-1 shows the wanted signal level as well as the adjacent channel interfering levels.

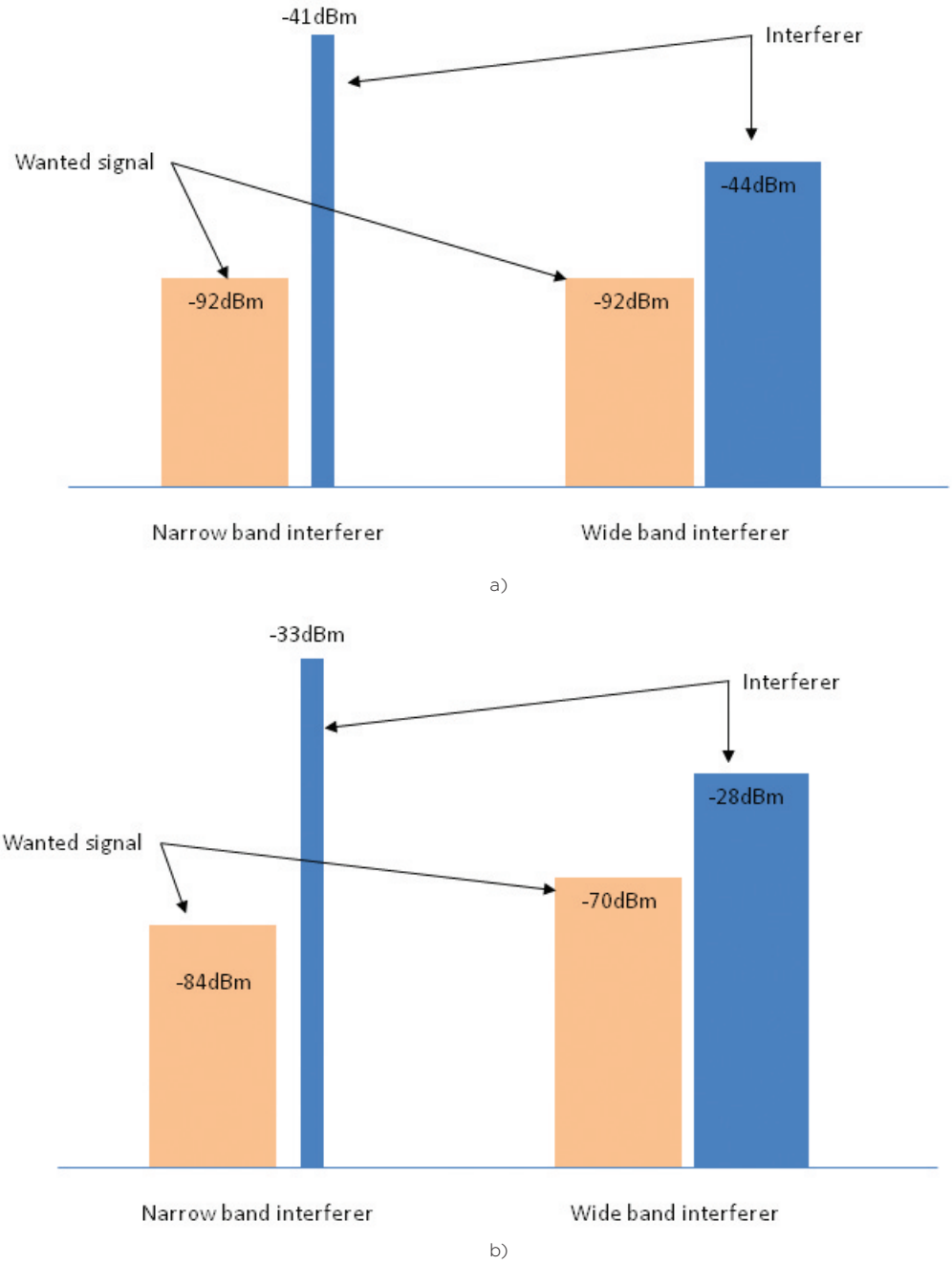

Figure 4-1 **Narrow band and Wideband interferer levels for a) local area eNB and b) home eNB**

The pass/fail criteria is based on having a throughput of at least 95% of the maximum throughput. These high signal levels will put stringent constraints on analog baseband filter design prior to the ADC. Being part of the integrated transceiver, the Radio420X's software-selectable baseband filters meet the adjacent channel selectivity requirements given their sharp rejection as shown in Figure 4-2.

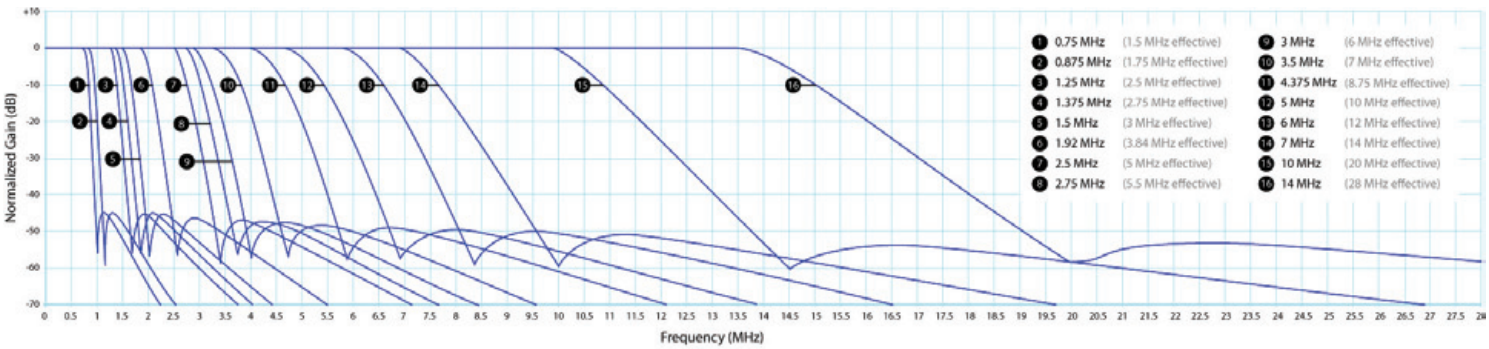

Figure 4-2 **Software-selectable baseband filters for adjacent channel selectivity**

The Radio420X's operation relies on the use of gain settings to avoid receiver saturation (ADC saturation mainly). Nevertheless, the Radio420X exhibits a -28 dBm input compression point (with gain set for maximum sensitivity), which lends itself well for operation in hostile environments with large adjacent channel interferers.

On the other hand, added noise due to reciprocal mixing from LO phase noise must also be accounted for. Assuming that the phase noise density is flat within the adjacent channel bandwidth, one can easily determine the added noise or infer the required maximum LO phase noise at a given offset.

The maximum LO phase noise at a 400 KHz offset in the case of the DCS1800 BTS can be determined as follows. From Table 4-2, the interfering GMSK signal at a 400 KHz offset is -34 dBm. If one wants to limit the reciprocal noise to 10 dB below the wanted signal level, then the noise level shall be less than -81 dBm. Therefore, the required phase noise shall be better than [-81-(-34)] dBm, i.e. -47 dBm within a 200 KHz bandwidth. Hence, the phase noise shall be better than -100 dBm/Hz. The Radio420X's measured phase noise is 108 dBc/Hz, which meets the minimum requirement with a margin.

Similar reasoning can be made for the LTE eNB. Consider a home eNB with a -70 dBm wanted signal and a -28 dBm 5 MHz E-UTRAN adjacent interferer at a 2.5025 MHz offset. The maximum phase noise shall be [-70dBm-10dB-(-28)] dBm, i.e. -52 dBm over a 5 MHz bandwidth or -119 dBm/Hz. This is met by the Radio420X with a 1 dB margin (see Table 3.3). However, a local area eNB requires better than -125 dBm/Hz; otherwise only 5 dB C/I shall be expected instead of 10 dB.

It is worth mentioning that more margin need to be considered in case of faded wanted signal and faded interferer as this is the case for DCS1800 BTS. One can set the extra margin for TI5 channel for instance equal to a reasonable level crossing threshold ρ in Rayleigh fading channel so that the level crossing rate (in No of fades per second) measured as $\sqrt{2\pi} f_d \rho e^{-\rho^2}$ is related to FER, with f_d being the maximum Doppler frequency.

4.3 Receiver intermodulation

Third and higher order mixing of two interfering RF signals can produce an interfering signal in the band of the desired channel. Intermodulation response rejection is a measure of the capability of the receiver to receive a wanted signal on its assigned channel frequency in the presence of two interfering signals that have a specific frequency relationship to the wanted signal. Interfering signals shall be continuous wave (CW) signals for the GSM BTS. For the LTE eNB, the interferer shall be a CW signal and an E-UTRA signal.

The intermodulation performance requirements are outlined in Table 4-3. Table 4-3 summarizes the wanted signal level and the mean power of the interfering signal.

Table 4-3 **Intermodulation performance requirement**

BTS type	Wanted signal mean power in dBm	Interfering signal mean power in dBm	Pass/Fail criteria
DCS1800 pico BTS (GSM)	-89	-49	Class II RBER < 2.0 %
Local area eNB (LTE)	-86.8 (-92.8+6dB)	-44	Throughput greater or equal to 95% of the maximum throughput
Home eNB (LTE)	-78.8 (-92.8+14dB)	-36	Throughput greater or equal to 95% of the maximum throughput

The following equation is typically used to determine the overall receiver IP3 requirements:

$$IP3 = P_i + (P_i - P_u + C/I)/2$$

Where P_i is the interfering signal level (e.g. -49 dBm for the DCS1800 pico BTS), P_u wanted signal (e.g. -89 dBm for the DCS1800 pico BTS) and C/I is the carrier over interference ratio. Herein, we set C/I equaly to 12 dB and 6 dB for GSM and LTE respectively. The required minimum IP3 is:

$$IP3_{DCS1800\ pico\ BTS} = -49 + (-49 + 89 + 12)/2 = -23\ dBm$$

$$IP3_{Local\ area\ eNB} = -44 + (-44 + 86.8 + 6)/2 = -19.6\ dBm$$

$$IP3^{Home\ eNB} = -36 + (-36 + 78.8 + 6)/2 = -11.6\ dBm$$

The measured IMD3 for the Radio420X is typically -58 dBc using a two tone test at -40 dBm. This results in an IP3 of -11 dBm, which meets the required minimum IP3 for the three cases above.

4.4 Blocking performance

Blocking characteristics is a measure of the receiver's ability to receive a wanted signal at its assigned channel in the presence of unwanted strong interferers which are in-band or out-of-band blocking. The levels of the wanted signal along with the blockers levels are show in Table 4-4 for the in-band blocker. For LTE eNB, these are 5 MHz E-UTRAN signal at a 7.5 MHz offset.

Table 4-4 **Blocking performance requirement**

BTS type	Wanted signal mean power in dBm	Interfering signal mean power in dBm	Pass/Fail criteria
DCS1800 pico BTS (GSM)	-92	-41dBm @ +/-600kHz to +/-1800MHz, -31dBm @ +/-1.6 to +/-1.8MHz, -23dBm @ +/- 3.0Mhz and up.	Class II RBER < 2.0 %. Allowed exceptions are less than 12 of which no more than 3 are consecutive.
Local area eNB (LTE)	-86.8 (-92.8+6dB)	-35	Throughput greater or equal to 95% of the maximum throughput
Home eNB (LTE)	-78.8 (-92.8+14dB)	-27	Throughput greater or equal to 95% of the maximum throughput

The receiver strip's compression point is based on the in-band blocking requirements in Table 4-4. The in-band blocking, at a 3 MHz offset for DCS1800 pico BTS, sets the constraint on the input compression point to -23 dBm. However, the Radio420X exhibits a -28 dBm input compression point, which is 5 dB and 1 dB too short to meet the respective limits of the DCS1800 pico BTS and home eNB. Given the head room from the noise floor, the Radio420X's RX variable gain amplifier can be operated 6 dB below its maximum level used for reference sensitivity and still be able to maintain an SNR above the required threshold.

With particular consideration for the DCS1800 pico BTS, the 3 MHz strong in-band blocker also needs to be seen from a second order intermodulation perspective as this would create a DC component on top of the weak wanted signal. This sets a stringent requirement for IP2, mainly for direct conversion receivers like the one used in the Radio420X. One should not expect to meet the 3 MHz in-band blocker test using the Radio420X unless the LO is shifted to operate the radio in Low IF mode. This mode is supported in the Radio420X but it requires extra baseband processing for image rejection. As far as LTE eNBs are concerned, this issue is of less importance as the DC subcarrier is left unused.

Added noise due to reciprocal mixing from LO phase noise also needs to be accounted for in LTE eNBs. Carrying the same assumptions as in Section 4.2 with respect to LO phase noise flatness, one can infer the required maximum LO phase noise at a 7 MHz offset. Consider the home eNB with a -78.8 dBm wanted signal and a -27 dBm 5 MHz E-UTRAN blocker at a 7 MHz offset. The maximum phase noise shall be [-78.8dBm-10dB-(-27)] dBm, i.e. -61 dBm over a 5 MHz bandwidth or -128.8 dBm/Hz. This is met by the Radio420X with a 7 dB margin (see Table 3.3).

On the other hand, the level for the out-of-band blockers are 0 dBm and -15 dBm for the PCS1800 pico BTS and local area/home eNB respectively. These define the filter rejection specifications in order to avoid signal path compression. The RX filter bank, as depicted in Figure 2.2 and Figure 2.3, uses a bank of band-pass SAW filters that provide a typical out-of-band rejection of 40 dB. This filter bank is preceded by a variable gain amplifier whose input compression point at 2 GHz is typically 2 dBm.

5 Conclusion

This paper has addressed some of the critical radio design requirements for GSM and LTE base transceiver stations. The requirements were mapped to frequently used radio performance metrics like compression points, intercept points, and noise figures. When projected onto the Radio420X's RF performance, one can easily see the potential of using the Radio420X for 3GPP radio design and prototyping. The Radio420X can be operated at any frequency from 300 MHz to 3.8 GHz in either FDD or TDD modes. Even if it's not very accurate, our analysis and discussion helps to educate, not only on how to use the Radio420X for prototyping, but also to help beginner radio designers gain a better understanding on how to interpret 3GPP radio performance specifications.

6 References

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[2] 3GPP TS 36 104: "E-UTRA Base Station (BS) radio transmission and reception".

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