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# Interference Issues between UMTS & WLAN in a Multi-Standard RF Receiver

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*Abstract*— **There is an increasing demand for single user equipment (UE) supporting multi standards in third generation communication systems and beyond. Nevertheless, integrating several standards in one UE increases the front-end design complexity due to the coexistence of several systems. This paper investigates one of these issues which is the signal interference between UMTS and WLAN applications. By considering the system issues, multi-standard operation and interfering effects in a multi-standard transceiver supporting UMTS and WLAN, the receiver requirements have been derived based on the existing 3GPP specifications. The derived constrains are generally valid for all types of receiver architectures. Therefore, they are applicable for selection of components such as LNAs and filters in a multi-standard receiver front-end regardless of the chosen architecture.**

Fig. 1. Illustration of a multi-standard user equipment supporting UMTS and WLAN standards.

## I. Introduction

Implementation of a multi-standard front-end intensifies some of the previous design challenges in conventional receivers [1]. One of the main challenges is the coexistence of several standards in one user equipment (UE). The interference in multi-standard receivers is a major problem because each desired signal may act as an interferer for the other received signals. Since it becomes desirable to use simultaneous operation in a multi-standard receiver, it is important to meet the requirements specified in the standard for each application by controlling the interfering power of the other signals in the same user equipment. In this investigation, the UMTS and IEEE 802.11g standards are selected as the case study [2], [3]. An example for the case study is when a user employs the single user equipment for receiving a UMTS FDD call simultaneously with transferring a file to the Internet/Network through WLAN connection. In this example, both transmitters of WLAN and UMTS and the UMTS receiver are operating at the same time. This scenario is illustrated in Fig. 1.

The RF requirements of a multi-standard receiver in the presence of noise and nonlinear distortions are investigated in this paper. The necessary design constrains are also derived. The receiver design must be in accordance with the derived requirements in order to obtain an acceptable compromise between the noise and third order intermodulation distortion. The derived constrains are not dependent on the specific receiver architecture and are applicable for all types of receivers. An example of a receiver RF front-end with digital-IF architecture is introduced to support the two standards operated simultaneously.
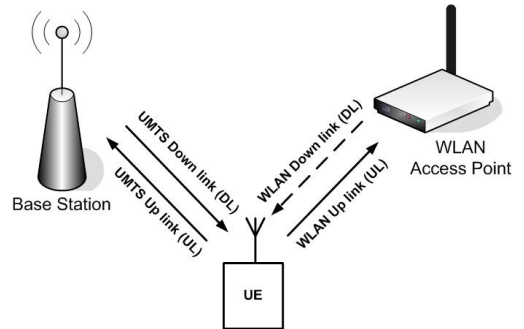
Numerous papers have been published that cover the different aspects of reconfigurable receiver architectures. Nevertheless, only few papers are found in the field of receiver architectures with concurrent operations, such as [4] and [5]. In [4], the theory, design, and applications of a novel concurrent multi-band low-noise amplifier are investigated. In [5], the design and practical implementation of multi-frequency RF front-ends using direct RF sampling is discussed. However, to the authors' knowledge, the investigation of interfering issues in multi-standard concurrent front-ends is still mostly an uncovered subject that requires more research to enhance the total performance of the entire system.

## II. Coexistence between UMTS and WLAN

According to the defined scenario of this paper, the UE enables both WLAN and UMTS to operate concurrently. Since UMTS is a FDD operating standard, both the uplink (UMTS UL) and downlink (UMTS DL) signals may exist at the same time with the separation in frequency domain. The duplexer is responsible of isolating these two signals in the 3G transceiver. However, the WLAN uplink (WLAN UL) and downlink (WLAN DL) are operating in different time periods due to the time duplexing (TDD) capability of the IEEE 802.11 standard. Therefore, in each moment, only one of the WLAN UL or DL may exist in the user equipment. For deriving the worst case requirements of the receiver, the desired signal considered is the received UMTS signal from the base station and the interference sources are defined as the internal blocking signals leaking from the WLAN and UMTS transmitters at the same transceiver as shown in Fig.1 with

solid-line arrows. The second probable case for this scenario is when the WLAN DL is active instead of WLAN UL while the UMTS transceiver operating at the same time shown in Fig. 1 with dashed-line arrows. In this case the received signal is in the range between -82 to -65 dBm (the sensitivity of the WLAN signal that depends on the data rates) which is well below the first case in comparison with the WLAN transmitted signal. Thus, to derive the most stringent requirement, the first case is investigated in this paper. The spectrum of the UMTS received signal (UMTS DL) and the UMTS transmit (UMTS UL) and WLAN transmit (WLAN UL) signals at the antenna ports is illustrated in Fig. 2.
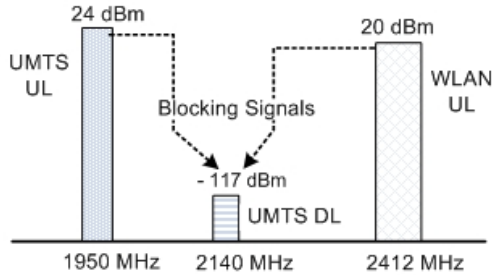


Fig. 2.   Illustration of frequency spectrum of UMTS UL, UMTS DL, and WLAN UL.

The UMTS UL from the UE is operating at a center frequency of 1950 MHz and the transmit power of 24 dBm (power class 3) which is the maximum average output power to derive the worst case requirement. The WLAN UL signal is a 20 dBm spectrum centered at 2412 MHz. The UMTS and WLAN main specifications are presented in Table 1.

TABLE I

UMTS AND WLAN SPECIFICATIONS FOR UE [2], [3].

|  | IEEE 802.11g | UMTS |
|---|---|---|
| Duplexing | TDD | FDD |
| Frequency | 2.4 - 2.4835 GHz | 1920 - 1980 MHz: UL |
|  |  | 2110 - 2170 MHz: DL |
| Receiver Sensitivity | -82 to -65 dBm | -117 dBm |
| Channel Bandwidth | 16.6 MHz | 3.84 MHz |
| Transmitter Power Level | 20 dBm (Europe) | 24 dBm (Class 3) |

## III. AN EXAMPLE OF A MULTI-STANDARD RECEIVER ARCHITECTURE

As it is mentioned in the introduction, the receiver requirements that are calculated in this paper are independent of the chosen architecture. As an example, the dual-standard architecture to support both the WLAN and UMTS received signals is depicted in Fig. 3. However, the results from this paper are still valid for any other chosen architecture. In the proposed architecture, the unique functionalities of each standard can be set in the digital signal processing (DSP) part by employing software-defined radios (SDR) [12].

A high isolation duplexer is employed to separate the UMTS received and transmitted signals with the parameters depicted in Table 2. The wideband mixer downconverts the UMTS

TABLE II

DUPLEXER PARAMETERS [8].

|  | Bandwidth | Insertion Loss | Attenuation |
|---|---|---|---|
| Transmitter | 60 MHz | 2.5 dB | 55 dB (2110 to 2170 MHz) |
| Receiver | 60 MHz | 2.0 dB | 70 dB (1920 to 1980 MHz) |

signal to the low-IF and the WLAN signal to the IF frequency, respectively. The channel selection and sampling for each signal are done separately. An appropriate sampling and IF frequency must be chosen to relax the design complexity of the digital to analogue converter, fulfill the IF and RF filtering and front-end linearity requirements. After the mixer, the UMTS receiver has a narrow band channel select filter. However, a wideband BPF filter for the WLAN receiver is employed. An ADC with better resolution is then required for the WLAN receiver to fulfill the SNR requirement.
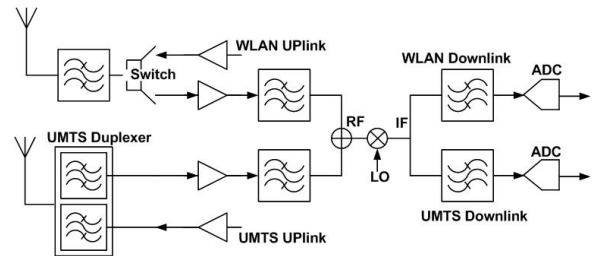


Fig. 3.   The proposed multi-standard receiver architecture.

## IV. RECEIVER REQUIREMENTS

The receiver must have adequate performance when receiving simultaneous UMTS and WLAN signals in one UE. For the UMTS receiver, it should meet the platform specifications in several tests defined in the 3GPP standard [2].

### A. Reference Sensitivity Level test case

The reference sensitivity level is the minimum input power at the antenna port of the receiver at which the bit error rate (BER) does not exceed 0.001 [2]. The maximum tolerable noise figure (NF) of the front-end is determined from the sensitivity test. The effective bit energy to noise density ($E_b/N_t$) including an implementation margin for various baseband imperfections is 7 dB to meet the BER requirement [10]. The minimum UMTS DL power level before de-spreading in the front end ($S_i$) is -117 dBm/3.84 MHz [2]. The duplexer loss (IL) is 2 dB [8], and the processing gain (PG) is 25 dB [7]. To meet the requirements specified in the standard, the acceptable noise and distortion level ($P_N$) after the duplexer is equal to

-101 dBm/3.84 MHz calculated from:

$$P_N = S_i - IL - (E_b/N_t)_{eff} + 10 \cdot \log(PG) \quad [\text{dBm}] \quad (1)$$

When the transmitters are turned off, the receiver noise power including antenna noise ($P_{N(actual)}$) is given by:

$$P_{N(actual)} = k \cdot T_o \cdot BW \cdot NF \quad [\text{W}] \quad (2)$$

Where $k$ is Boltzmann's constant, $T_o$ is the standard noise temperature and $BW$ is the signal bandwidth [9]. It is assumed that the antenna noise temperature is equal to $T_o$. When the transmitters are turned on, the actual noise power is:

$$P_{N(actual)} > k \cdot T_o \cdot BW \cdot NF + P_{NTx1} + P_{NTx2} \quad [\text{W}] \quad (3)$$

Where $P_{NTxn}$ is the transmitter noise leakage power in the Rx band at the receiver input. This equation is illustrated in Fig. 4.

If the transmitters are turned off, the only contributor to noise is the receiver noise power including the antenna noise. Thus, the acceptable noise and distortion level ($P_N$) is equal to receiver plus thermal noise ($P_{NRx1}$) resulting to a receiver noise figure of 7 dB by using Eq. (2). To make a room for the noise leakages from WLAN and UMTS transmitters in the receiver noise budget, the receiver noise figure must be reduced consequently. The disturbance budget that has been chosen allows 1 dB noise figure reduction in the receiver. After all filtering, amplification and suppression, the coming disturbances from the UMTS UL ($P_{NTx1}$) and WLAN UL ($P_{NTx2}$) in UMTS DL are sharing the remaining noise and disturbances equally that leads to the noise power budget defined in Fig. 4 [11]. Other choices of NF reduction and allowed transmitter noise leakages may be made according to a cost analysis for the transceiver.
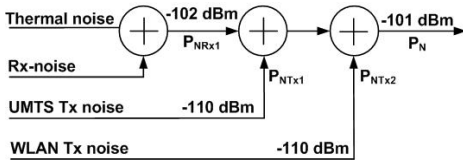


Fig. 4. The noise power budget.

The acceptable UMTS UL and WLAN UL noise power in UMTS DL (at the antenna port) must not exceed -110 dBm with respect to the noise budget. The allowed out-of-band power of WLAN is 50 dB below the Power Spectral density (PSD) of the transmitted signal [3]. The power level of the WLAN transmitter is 20 dBm (the PSD is -52 dBm/Hz). Therefore, the WLAN PSD in the UMTS receive-band is -102 dBm/Hz or -36dBm/3.84 MHz at the WLAN antenna. To obtain a level of -110 dBm, it is required to provide an isolation of 74 dB. This doesn't seem realistic to be achievable only by the separation of antennas and filtering in the receiver path. Thus, a reduction of the noise in the WLAN transmitter is required.

## B. Intermodulation

The intermodulation product calculation is important in order to find the necessary constrains that guaranty the linearity of the receiver. Three different intermodulation tests are examined for the proposed multi-standard receiver and the linearity constrains have been defined:

- Minimum in-band third order intercept point ($iIP_3$)
- Minimum out-of-band receiver's $iIP_3$ (UMTS UL)
- Minimum out-of-band receiver's $iIP_3$ (WLAN UL)

The minimum required $Nth$ order intercept point can be calculated from Eq. (4) [11] Where $N$ is the non-linearity order, $iP_{INT}$ and $iP_{DIS}$ are the interference power and the acceptable level of distortion power (referred to the input) respectively [11]:

$$iIP_N \geq \frac{N}{N-1} \cdot iP_{INT} - \frac{1}{N-1} \cdot iP_{DIS} \quad [\text{dBm}] \quad (4)$$

The power level of the wanted signal in the intermodulation test scenario is -114 dBm ($P_{R,DPCH}$) (3dB above the reference sensitivity level) at the antenna port [2]. It is assumed that the intermodulation can be treated as noise [7], and thus the maximum acceptable level of the noise and interference ($P_{N+I}$) for this scenario is -98 dBm and calculated from:

$$P_{N+I} = P_{R,DPCH} - IL - (E_b/N_t)_{eff} + 10 \cdot \log(PG) \quad (5)$$

*1) In-band Test:* The two-tone test has been defined to set the requirements for the $iIP_3$ of the receiver. The BER shall not exceed 0.001 in the presence of the two signals defined as a CW signal ($I_{ouw1}$) and a modulated signal ($I_{ouw2}$) with equal power of -46 dBm. The interferers are located at the offset frequencies of 10 and 20 MHz, respectively. The third order distortion caused by these two signals in the desired channel is added on top of the wanted signal. By proper choice of filters in the receiver, the signal leakages from the WLAN and UMTS UL can be sufficiently suppressed. Therefore, the direct blocking effect is avoided. A budget distribution is assumed for the intermodulation test that covers all the different noise and distortions as presented in Table 3.

TABLE III

BUDGET DISTRIBUTION FOR DISTURBANCE [7].

| Disturbance | Percentage | Level |
|---|---|---|
| Noise (antenna, receiver, WLAN and UMTS UL) | 50% | -3 dB |
| Intermodulation products | 15% | -8 dB |
| Modulated interferer blocking | 15 % | -8 dB |
| CW interferer blocking | 15% | -8 dB |
| Oscillator noise | 5% | -13 dB |

The acceptable power level of each blocking signal or intermodulation product after the duplexer is ($P_{N+I}$) − 8 dB = -106 dBm. The receiver $iIP_3 \geq -19dBm$ is calculated from

Eq. (4) . The receiver selectivity must limit the blocking effect of the two interfering signals. The required selectivity at 10 and 20 MHz frequency offsets is calculated equal to 60 dB using:

$$Selectivity(10/20 \text{ MHz}) \geq \text{iP}_{\text{INT}} - (\text{P}_{\text{N+I}} - 8\text{dB}) \quad (6)$$

*2) Out-of-band CW blocker:* There is a possibility that a CW blocker in combination with either of the WLAN or UMTS UL signals creates an intermodulation product on top of the desired signal. Therefore, it sets an additional $iIP_3$ requirement on the receiver. According to the out-of-band blocking test defined in the standard, the CW blocker ($P_{Blk}$) with the power level of -44, -30, and -15 dBm may exist at the frequency offset of 15, 60 and 85 MHz, respectively. The out-of-band intermodulation requirement for both leakages is calculated in the following section.

*a) UMTS UL leakage:* The test case is illustrated with dash-line in Fig. 5. The CW interferer and the UMTS transmitter leakage are suppressed to -60 dBm and -46 dBm, respectively after passing through the duplex filter (providing 30 and 70 dB attenuation, respectively [8]).
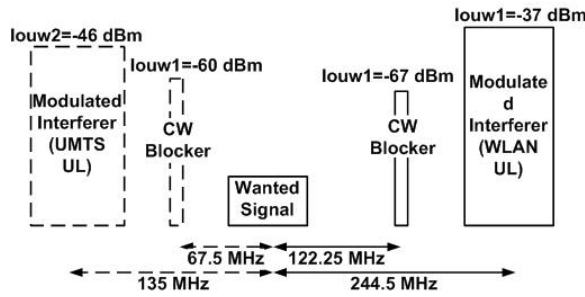


Fig. 5. Out-of-band intermodulation test (WLAN UL solid line, UMTS UL dash-line).

To calculate the $iIP_3$ product, the two signals are replaced by an equal value [7]:

$$iP_{INT} = \frac{1}{3} \cdot (-46) + \frac{2}{3} \cdot (-60) = -55.3 \quad [\text{dBm}]$$

Because of the large frequency offset, the blocking effects are negligible and the allowable interference level is $P_{N+I} - 3$ dB (noise contributes 50 percent of the power). The duplexer insertion loss is assumed to be 2 dB (IL). Therefore, the minimum requirement for the third order intermodulation is calculated from Eq. (4):

$$iIP_3 \, (67.5/135 MHz) \geq -32.5 \quad [\text{dBm}]$$

*b) WLAN UL leakage:* The CW blocker is located at 122.25 MHz offset and the modulated interferer (the UMTS UL signal) is placed at the 244.5 MHz offset from the UMTS DL as illustrated in Fig. 5 with solid-line. The 20 dBm leakage from the WLAN UL signal is attenuated 57 dB by the duplex filter [8]. The CW blocker is suppressed 52 dB by duplex filter and reaches -67 dBm (out-of-band blocker at distances more

than 85 MHz is -15 dB [2]). The two signals are replaced by an equal value [7] which is:

$$iP_{INT} = \frac{1}{3} \cdot (-37) + \frac{2}{3} \cdot (-67) = -57 \quad [\text{dBm}]$$

With similar discussion to the UMTS UL, the $iIP_3$ is derived from Eq. (4) to:

$$iIP_3 \, (122.25/244.5 MHz) \geq -35 \quad [\text{dBm}]$$

From the intermodulation test calculations, it comes out that the requirement for in-band $iIP_3$ is more stringent than the requirement for out-of-band third order intermodulation. Moreover, it should be mentioned that the duplexer specifications have great impact on the out-of-band $iIP_3$ requirement calculations as it is mentioned in the previous section.

*C. Image Rejection capability*

The selection of the local oscillator frequency in this paper is assumed to be done in a way to avoid both the intermodulation and image problem at the same time. Therefore, the image-rejection capability of the receiver can be determined from the out-of-band blocker test separately. The necessary suppression for the blockers located at more than 85 MHz offset is calculated equal to 86 dB from Eq. (7) noting that the noise has the 50 percent contribution:

$$Rejection(> 85MHz) \geq P_{Blk} - (P_{N+I} - 3dB) \quad (7)$$

Therefore, to meet the requirement, the CW blockers in offset frequencies more than 85 MHz must be attenuated equal or more than the image rejection value of the receiver.

TABLE IV
SUMMARY OF RECEIVER REQUIREMENTS.

| Rx parameter | Requirement |
|---|---|
| Noise figure [dB] | $\leq 7$ |
| Selectivity [dB] | |
| In-band selectivity (10 / 20 MHz) | $\geq 60$ |
| Image rejection ($\geq$ 85MHz) | $\geq 86$ |
| Intermodulation [dBm] | |
| $iIP_3$ (10/20 MHz) | $\geq -19$ |
| $iIP_3$ (UMTS UL leakage) | $\geq -32.5$ |
| $iIP_3$ (WLAN UL leakage) | $\geq -35$ |

## V. CONCLUSION

The UE receiver requirements have been derived for a multi-standard front-end supporting UMTS and IEEE 802.11g simultaneously. The results are valid for any chosen architecture and are outlined in Table 4. The FDD operation of UMTS allows both the transmitter and receiver to operate at the same time. In addition to UMTS signal, one of the uplink or downlink signals of the WLAN exists. Thus, due to the coexistence of all these signals, a more stringent requirement is applied

to the receiver linearity requirement specially in-band $iIP_3$. Beside the linearity requirements, the noise level plan of the receiver must be adjusted for the multi-standard operation. Thus, to achieve to an acceptable performance according to the specified requirements in the 3GPP standard, the noise figure of the conventional UMTS receivers must be reduced to a lower amount by the proper design of the transceiver as it is mentioned in the paper.

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