A Hybrid Galileo/W-CDMA Receiver Architecture for Mass-Market Applications

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INTRODUCTION

In the coming years the location of mobile phones or personal digital assistants (PDAs) will become by far the market leader in the area of personal navigation applications. Market surveys forecast that the global GPS receiver market for automotive and mobile phone applications could reach around 55 million units in 2005. About 73% of this market, corresponding to around 40 million units, is expected to fall into the category of mobile phone applications.

The planned GNSS modernization will undoubtedly further expand and improve applications for users in many fields by allowing combined use of such systems in hybrid receivers. These GNSS advances include the implementation of the Galileo system, now entering the development and validation phase under the cooperative management of the European Commission (EC) and the European Space Agency (ESA), as well as planned improvements in the U.S counterpart, GPS.

Taken all this into account, an important step into the market for Galileo is the in-time availability of hybrid Galileo/GPS receiver in combination with cellular network positioning capability for consumer applications. This is the main idea behind the GAWAIN project – the development of an integrated GNSS/UMTS (Universal Mobile Telecommunications System) receiver, which provides seamless indoor/outdoor navigation and communication capability, using GPS/Galileo and 3G/UMTS for transportation and tourism (for mass market applications), combined with suited LBS maps and information data services. The Galileo W-CDMA Integrated Navigation (GAWAIN) project is partially funded by the EC. The consortium is led by IfEN GmbH in Germany and consists of Infineon Technologies AG, Germany, the Austrian company DICE and the Research Institutes for Integrated Circuits (RIIC) and for Information and Communication Engineering (ICIE) of the University of Linz, Austria.

The paper will present an overall overview of the GAWAIN project, its 3-step design approach to finally come out with a running receiver prototype at project end. The project itself has been started with the definition of the user requirements. Emphasize is put here on the intelligent transport and ubiquitous tourism market. Results of those market requirements will be presented. Then, in order to reach the designated goal of an integrated GNSS/UMTS receiver, the task currently carried out is the architectural design with main emphasis on Advanced UMTS Radio Frequency (RF)-Transceivers, Advanced Galileo/GPS Receiver Concepts and the Integrated Navigation & Communication Concept. Preliminary results of analysis and architectural design of these concepts will be presented.

MARKET ASSESSMENT AND DEFINITION OF USER REQUIREMENTS

With respect to the GAWAIN objectives four significant groups can be distinguished within the intelligent transport segment, i.e. road, rail, intermodal freight and intermodal passenger transport. Basically two main classes can be identified for the requirements definition: The consumer class and the professional class. The former is targeted on high-volume solutions for in-car Navigation / Communication applications and is considered as the primary target group for GAWAIN. According to the latest estimates by the research firm Strategic Analytics the worldwide market value for in-vehicle telematics systems will be 7.4 billion US$ in 2005 and about 8.4 billion US$ by the year 2010. The professional class is characterized by more specialized Navigation / Communication solutions for the medium/low-volume market, mainly focusing on the container and trailer market. The need for wireless communication and determination of accurate position data can be identified as the lowest common denominator of many of those applications.

Some basic characteristic requirements for the consumer class applications include e.g. low hardware costs, a good navigation coverage (also in urban environment), position accuracy of at least 5-10 meters and availability of two-way communication for telematic data etc. For the professional sector, which involves more sophisticated applications, several additional aspects have to be considered, e.g. special hardware robustness, indoor navigation coverage, low power consumption, and global/continental communication system compatibility etc.

Regarding the tourism segment GAWAIN focuses particularly on solutions for the LBS market. The term *LBS* has been excessively strained in recent years and many former revenue forecasts were quite overoptimistic indeed. Nevertheless the market prospects for mobile solutions based on combined navigation and communication capabilities are considered to be still promising. According to Strategic Analysts consumer location applications will generate over 8 billion US$ in global services in 2008.

For the tourism market the following LBS segments are of particular interest: Location based *Information*, *Billing* and *Safety* Services. A crucial factor for all kinds of personal navigation solutions is of course a high degree of hardware integration resulting in compact and flexible devices. An essential requirement for the information services is the wireless provision of appropriate and up-to-date geo data, e.g. maps, routing, points of Interest, public transportation stations etc., all related to the accurate current position of the user. Due to the large amount of data that is typically transferred, at least if the LBS includes maps and/or multimedia contents, it is necessary to have a communication link which provides high data rates, like it is the case with UMTS.

UMTS AND GALILEO/GPS SIGNAL STRUCTURES

To determine the possible solutions, if any, of a close GNSS-UMTS integration, first of all we have to take a look on the signal structures of Galileo on one hand and UMTS on the other hand. As already pointed out, both GNSS systems, the modernized GPS as well as the new European Galileo, will be based in future on DS-CDMA technology with a pilot channel. The key parameters of the signal structure of Galileo as well as of the European 3G mobile communication standard UMTS will be briefly discussed within the next sections.

UMTS Signal Structures

The knowledge of statistical signal properties is important for the system design of the RF front-end (RF-FE). Deriving parameters like Peak-to-Average-Power Ratio (PAR) is needed for e.g. level planning, since the average signal power that is specified in the UMTS-TCs alone does not allow a derivation of the peak signal levels. Knowledge of the peak signal levels is essential in RF-FE system design, since signal clipping may severely impair the transceiver performance. The detailed spreading and modulation procedures for the UMTS DL-PCHs can be found in [1, 2].

The PAR can be derived from the Complementary Cumulative Distribution Function (CCDF) shown in 3. The PAR is defined as the difference between peak and mean power for a CCDF of 0.1%. For the case of 3 DPDCHs the PAR value shown in Fig. 3 is 9.1 dB. It is clearly visible, that larger numbers of DPDCHs result in much higher PAR values. The upper bound of the PAR for Down-Link (DL) signals can be estimated from the case with 25 DPDCHs and is in the range of 14 dB.

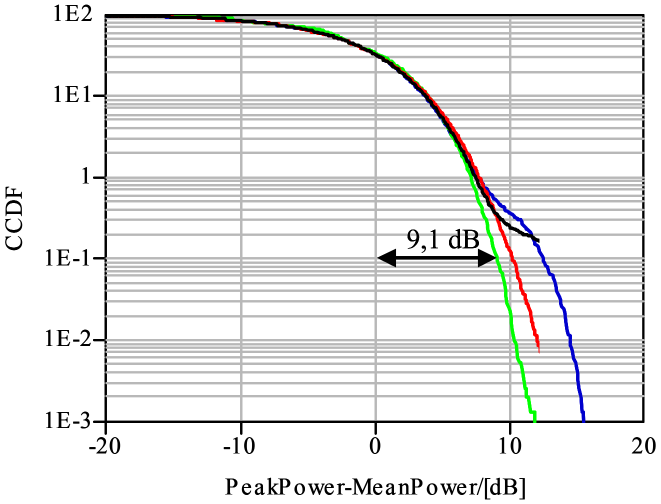

Fig. 3: CCDF vs signal power of a DL-UMTS signal (CPICH, PCCPCH, PSCH, SSCH+3 DPDCHs (green), 9 DPDCHs (red), 17 DPDCHs (blue) and 25 DPDCHs (black))

The UMTS standard [3] specifies a RRC filter for pulse shaping, which determines to a large degree the spectral properties of the UMTS signals. The impulse response $g_{RRC}(t)$ of the root-raised cosine (RRC)-filter with roll-off factor α and chip duration T_C is defined by

$$G_{rc}(f)=\begin{cases} T_C & |f|<\frac{1-\alpha}{2T_C} \\ T_C\cos^n(\frac{\pi T_C}{2\alpha}\left(|f|-\frac{1-\alpha}{2T_C}\right) & \frac{1-\alpha}{2T_C}\leq|f|\leq\frac{1+\alpha}{2T_C} \\ 0 & |f|>\frac{1+\alpha}{2T_C} \end{cases}$$

The pass-bandwidth of the above defined filter equals (1+ α)/2T_C, which results to 2.34 MHz for UMTS (α=0.22, T_C≈260 ns). Fig. 1 shows the impulse responses of an RRC and an RC filter. The RC response results due to the RRC-filtering in the transmitter and the receiver (matched filter). It is clearly visible, that only the RC response is inter-symbol interference (ISI) free (zero crossing exactly at multiples of T_C).

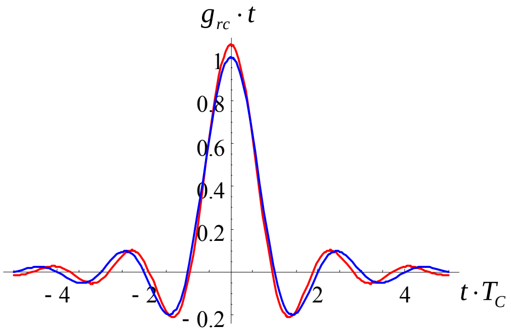

Fig. 1: RRC (red) and RC (blue) impulse response.

Galileo/GPS Signal Structures

For consumer applications in general and the transportation and tourism applications, which are the main focus of the GAWAIN project, in particular, the navigation signals transmitted at the L1 (1574.42 MHz) carrier will be the ones of highest commercial interest. Using only a single-frequency band, the receiver needs only one front-end. Processing of another carrier frequency (for example, GPS L2C at 1227.6 MHz) would allow a precise correction of the ionospheric delays. Such an improvement, however, is unnecessary for consumer-oriented positioning accuracy requirements at the 10-20 meter level. Designing a single-frequency receiver is generally considered to be substantially easier and less costly than building a multiple-frequency receiver.

Three navigation signals will be available at L1 within the next few years. This includes the well-known GPS C/A code and the Galileo Open Service (OS) signals. Our working hypothesis for the Galileo OS signal foresees two components, one data-free and one data-bearing channel. Assumed parameters are shown in Table 1. Further details of the Galileo signals can be found in [4].

	Modulation	**Chip Rate**	**Bit/Symbol Rates**	**Code Structure**
GPS	BPSK(1)	1.023 Mcps	50 bps	Gold (1023)
Galileo OS-B	BOC(1,1)	1.023 Mcps	125 sps	8184
Galileo OS-C	BOC(1,1)	1.023 Mcps	Data-free	Tired code: 25 x 8184

Tab. 1. Comparison of properties of GNSS signals at L1 frequency

The foreseen BOC (Binary Offset Carrier) modulation of Galileo provides better multipath and receiver noise performance compared to the GPS BPSK modulation. However, acquisition and tracking of BOC signals requires new techniques, not yet available today. Achieving an efficient and reliable BOC acquisition and tracking capability, is one of the currently open issues, not yet solved.

Fig. 2 illustrates the L1 signal environment according to the current Galileo baseline plus current and future GPS signals. In the new baseline, the BOC(14,2) was substituted by $\mathrm{BOC}_{\cos}$(15,2.5) for the PRS on L1. In addition, the OS signal has changed from BOC(2,2) to BOC(1,1) to ensure the necessary compatibility with GPS [4].

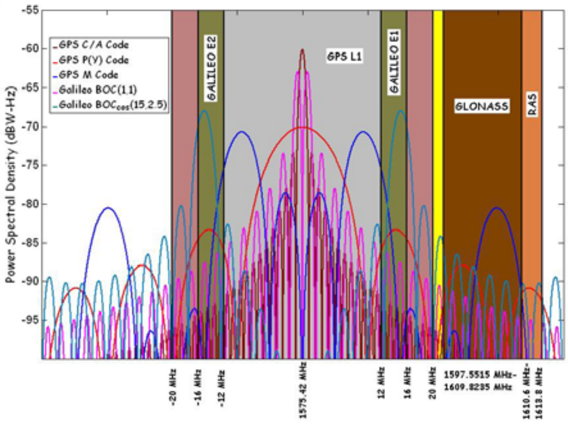

Fig. 2: Galileo Frequency Spectrum

In general, each Galileo frequency will feature a so-called Pilot-signal, which is a data-less channel that can be tracked coherently. The signals are modulated onto the so-called I- and Q-channels, i.e. they are modulated onto the same carrier with a relative phase shift of 90°. This is equivalent to a QPSK modulation. The symbol-rates range from 50 to 1000 sps. Forward error correction will be applied to the data, resulting in a data-rate of 25-500 bps.

OVERALL ARCHITECTURAL DESIGN

Advanced UMTS Receiver Concepts

The design of future generation receiver concepts involves a number of challenges, including the analogue radio frequency (RF) front end as well as the digital back end for baseband processing. Besides the demands for best performance, highest integration and smallest form factor there are always requirements for ultra low power consumption to achieve a long operation time. Those contradictions can only be solved by means of modern and sophisticated architectural concepts. The design techniques are mainly based on realistic modeling and simulations from system to chip level for the analog and digital part.

RF Front-End Part

Various RF front-end architectures are established for the reception (RX) of RF frequencies, including heterodyne low-IF and direct conversion receiver (DCR) depicted in Fig. 3 [5]. The pre-dominant architectures in current cellular RF front-end solutions use direct conversion between the RF frequency and base-band. Heterodyne architectures are rarely found these days.

The DCR architecture (also called homodyne architecture) is preferable, due to the fact that most of the gain and the channel selection are performed in the analog baseband section. This saves the first mixer and the first LO. Furthermore, the IF-amplifiers and the IF-filter (in most application an external SAW filter) can be replaced by low-pass filters and baseband amplifiers that are amenable to monolithic integration. Moreover, also the image problem of heterodyne receiver vanishes.

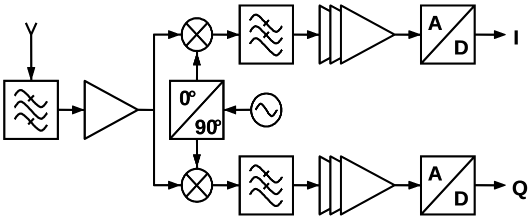

Fig. 3: Direct Conversion Receiver Architecture

The DCR topology entails a number of issues that do not exist or are not as serious in a heterodyne receiver [6]. Since in a homodyne topology the downconverted band extends to zero frequency, offset voltages can corrupt the signal and, more importantly, saturate the following stages. There are three several possibilities how DC offsets are generated.

First, the isolation between the local oscillator (LO) port and the inputs of the mixer and the low-noise amplifier (LNA) is not infinite. Therefore, a finite amount of feed through from the LO port to the mixer or the LNA input always exists (see Fig. 4). This LO leakage arises from capacitive and substrate coupling and, if the LO signal is provided externally, bond wire couplings. This leakage signal is now mixed with the LO signal, thus producing a DC component at the mixer output. This phenomenon is called self-mixing. A similar effect occurs if a large interferer leaks from the LNA or mixer input to the LO port and is multiplied by itself. A time varying DC offset is generated if the LO leaks to the antenna and is radiated and subsequently reflected from moving objects back to the receiver.

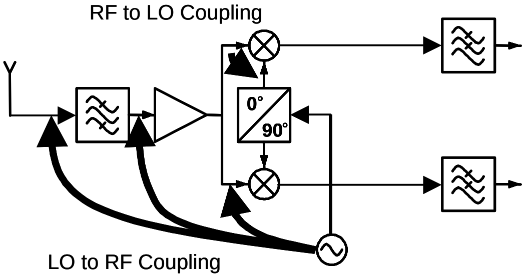

Fig. 4: LO to RF and RF to LO coupling for DCR

Large amplitude modulated signals that are converted to the baseband section via second order distortion of the IQ mixers may also lead to time varying DC offsets (see Fig. 5). The spectral shape of this signal contains a significant component at DC accounting for approximately 50% of the energy. The rest of the spurious signal extends to twice the signal bandwidth before being downconverted by the second order nonlinearity of the mixers. In order to prevent this kind of DC offset, a large second order Intercept Point (IP2) of the IQ mixers is necessary.

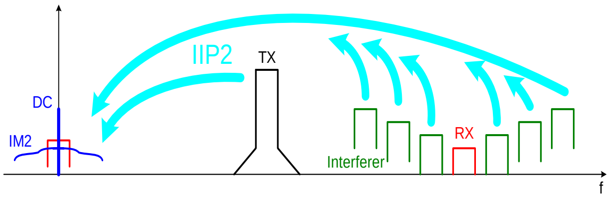

Fig. 5: DC-offset generated by IQ-mixer IP2

3GPP compliant receivers need 80 dB gain. Most of this gain is contributed by the baseband amplifiers. That means that even small DC offsets (in the range of several mV) at the mixer outputs may lead to DC levels sufficient to saturate the analogue-to-digital converters (ADCs).

In TDMA (time division multiple access) systems idle time intervals can be used to carry out offset cancellation. This would be a practical solution for the 3GPP-TDD (Time Division Duplex) mode. It cannot be used for offset cancellation in the FDD (Frequency Division Duplex) mode because of the continuous signal reception. Here, the natural solution for DC offset cancellation is high-pass filtering. Since the signal band extends from DC to approximately 2 MHz, a high-pass filter with a cut-off frequency of several kHz results in an acceptable degradation of the system performance. This approach is only possible because of the wideband nature of the UMTS signal.

Digital Baseband Part

Although the penetration rate of UMTS is currently accelerating, the dominant system for the next couple of years will be GSM/GPRS based. Therefore, a companion chip acting as a UMTS extension to 2.5G wireless modem baseband chip set solutions is the optimum choice for a 3G system for the next few years. This co-processor will implement all necessary UMTS physical layer baseband signal processing.

The design of such a co-processor is typically based on a central DSP core and memory accompanied by a group of highly optimized and dedicated hardware peripherals executing most of the system's signal processing tasks with very low power consumption. It has to incorporate the digital signal processing functions necessary to exchange raw binary data with a base station of a 3G system like UMTS-FDD. These functions include (Fig. 6):

- Cell search
- Power delay profile estimation
- Rake finger processing
- CDMA (code division multiple access) modulation
- Channel en- and decoding
- UMTS timing signal generation and RF control

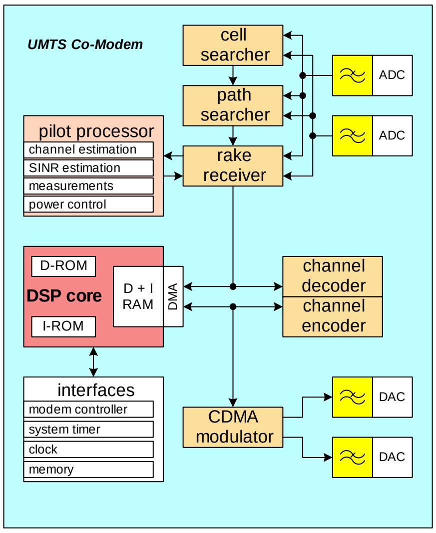

Fig. 6: UMTS baseband co-processor architecture

Combined Galileo/GPS Receiver Concepts

The hybrid Galileo/GPS receiver architecture described in this paper is designed to meet the requirements of seamless indoor/outdoor navigation capability, using Galileo and GPS signals in combination with 3G/UMTS cellular network positioning capability for transportation and tourism (for mass market applications), combined with suited LBS maps and information data services.

The hybrid Galileo/GPS receiver architecture has to operate in two distinct modes. One is stand-alone reception where assistance data from the UMTS cellular network are not available. In this mode of operation, the receiver first performs code acquisition, followed by tracking, where it decodes the data overlay of the navigation message. For weak-signal environments encountered in dense urban areas, however, the receiver relies on assistance data delivered through the UMTS wireless communications network to aid signal acquisition. In this A-GPS or in future A-GNSS mode (A-GPS/Galileo) particularly designed to meet the needs of location based services, a receiver neither tracks the satellite signal nor decodes the data overlay. Instead, it just performs a short “single-shot” measurement.

This single shot measurement is similar to the acquisition process of traditional GPS receivers. The aim of this process is to achieve synchronization between the locally generated codes in the receiver and the spreading codes of all visible satellites. The assistance data, such as the 3GPP’s A-GPS protocols, provide an estimate of which satellites are currently visible together with their Doppler frequency shift. They therefore significantly reduce the search space, such that mainly the code offsets of the GNSS signals are unknown. This, in turn, reduces the signal processing complexity. Furthermore, the assistance data deliver the entire data overlay of the satellite signals, so that signal tracking is not needed.

An overview of the combined Galileo/GPS receiver is shown in Fig. 7. This architecture consists of a common RF front-end for all openly accessible GPS and Galileo satellite signals in the L1-band. After sampling and analog-to-digital conversion (ADC), the receiver performs parallel despreading. The received complex baseband signal is multiplied in parallel with the spreading codes of all visible satellites. For each satellite, the received signal is multiplied in parallel with the different code delay offsets. These products are then accumulated to complete the cross-correlation function.

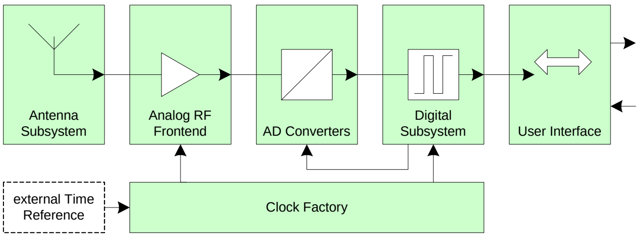

Fig. 7: Hybrid Galileo/GPS Receiver Concept

The difference to traditional acquisition is that the acquisition process of the single shot measurement receiver has to provide the same accuracy as traditional receivers achieve with delay locked loops (DLL) during the tracking process.

Supplementary measures for the BOC signals are necessary due to the multiple correlation peaks of the auto-correlation function. Carrier tracking is done using a phase-locked loop (PLL). Coherent correlation combined with differential or non-coherent correlation will be done for the pilot channel and the data channel.

A hybrid Navigation solution will be implemented in order to make use of assisted data delivered through the UMTS wireless communications network as well as to make use of the methods for positioning specified in the 3GPP/UMTS standard to supplement satellite-based navigation.

Digital Baseband Processing

For the tracking process and also for hardware acceleration of the A-GNSS single-shot measurements, the first digital hardware components after the AD conversion will be an Fs/4 demodulator (Fs: sampling frequency) moving the signal frequency band down by a fixed unregulated value of a quarter of the sampling frequency. This demodulator is followed by a polyphase lowpass filter. The filter selects the desired signal band and performs a subsampling of the data by a factor of 2. The passband of the lowpass filter for the GPS C/A code has a bandwidth of 2.046 MHz, that for the Galileo L1 BOC(1,1) will be 4.092 MHz.

New signal processing challenges arise with the transition from GPS only to combined Galileo/GPS, e.g. due to the BOC Modulation scheme or longer PRN sequences, which require high bandwidth signal processing capabilities of high complexity. Therefore, a flexible architecture that enables reuse of communication and signal processing components throughout the different navigation standards is a possible solution for a multi-standard receiver. The proposed architecture for despreading and correlation during the tracking mode is shown in Fig. 8. The received signal can either be correlated with the GPS C/A code or with a Galileo PRN code. The key issue in this architecture is the clock generation unit. Besides generating an appropriate chipping clock for the respective standard, it has to detect epoch boundaries, and generate synchronization signals (e.g. for switching between navigation standards).

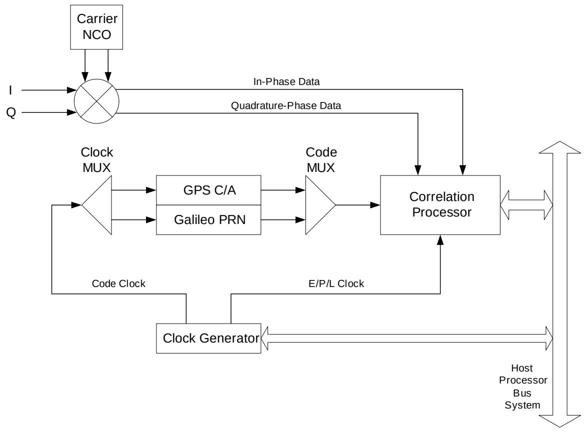

Fig. 8: Despreading and Correlation Architecture

The same principle can be applied to the correlation processor for tracking mode. Even though Galileo BOC signals require additional correlators (very-early and very-late code replicas besides the early, prompt, and late correlators for GPS C/A code), the basic architecture remains the same. It is therefore possible, to form a combined correlation processor architecture, where the early-prompt-late correlator structure is used for both Galileo and GPS signals, while the additional correlators required for Galileo are activated only on demand. This allows to switch between Galileo and GPS signals during runtime.

CHALLENGES FOR UMTS-GNSS INTEGRATION

Interference Issues

The continuous transmission during an active UMTS connection has to be considered carefully during the prototype design. The allowed spurious emissions by the UMTS standard [3] does not account for the L1 frequency band allocated for Galileo and GPS, which covers the range 1559 MHz – 1594 MHz, as shown in Fig. 2. This can be seen in the following subsection which is repeated from the standards document.

UMTS Spectrum Emissions

UTRA/FDD is designed to operate in the several paired frequency bands. For the work within GAWAIN only operation in frequency band I, which covers 1920 – 1980 MHz for the uplink and 2110 – 2170 MHz for the downlink, is considered.For the spurious emissions of an UMTS mobile (user equipment (UE) is the commonly used term in the 3GPP documents) defined in [3], the following definitions apply:

Spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out of band emissions.

The frequency boundary and the detailed transitions of the limits between the requirement for out band emissions and spectrum emissions are based on ITU-R Recommendations SM.329. The minimum requirements for an 3GPP compliant UE transmitter according to 3GPP allow to have spurious emissions of up to -30 dBm measured within a bandwidth of 1 MHz. For comparison purposes, the sensitivity of the Galileo/GPS receiver module to be developed for the GAWAIN prototype will be around -130 dBm.

To evaluate the possible impairment of the Galileo/GPS receiver due to the UMTS transmitter the following steps have to be carried out within GAWAIN

1. Definition and generation of a CW and an UMTS spurious signal with the maximum allowed power according to TS 25.101 by means of simulation
2. Evaluation of the Galileo/GPS receiver performance degradation if disturbed by the signals from step 1
3. Evaluation of the maximum allowed spurious emission power from the UMTS UE transmitter for successful Galileo/GPS receiver performance

Depending on the results of this study, further work will be defined.

Another interference issue can result from crossmodulation. If the UE transmit signal is combined with a strong signal within the Galileo/GPS L1 receive band at some nonlinearity (e.g. the nonlinear behaviour of the Galileo/GPS RF front-end LNA) a crossmodulation term proportional to $s_1(t)s_2^2(t)$ appears, where $s_1(t)$ represents the signal within the GNSS receive band and $s_2(t)$ represents the UMTS transmit signal. In the spectrum, the crossmodulation signal appears in the Galileo/GPS L1 frequency band around the signal $s_1(t)$. From the allowed degradation of the Galileo/GPS receiver performance, the maximum tolerable nonlinearity of the Galileo/GPS RF front-end LNA has to be determined by means of simulation in a procedure according to the one described above.

CONCLUSION

An important step into the market for Galileo is the timely availability of hybrid Galileo/GPS receiver in combination with wireless communications network positioning capability for consumer applications. This paper has shown the first development steps of the GAWAIN project based on the advanced receiver concepts. The initial ideas regarding an integrated GNSS/UMTS receiver architecture were presented in order to meet the important requirements of seamless indoor/outdoor navigation and communication capability for transportation and tourism, combined with suited LBS maps and information data services. The next steps of the GAWAIN project will be related to the detailed hardware and software design of the integrated GNSS/UMTS receiver itself.

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