

Hybrid Galileo/W-CDMA Receiver Prototype for Mass-Market Applications

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BIOGRAPHY

Guenter Heinrichs received a Dipl.-Ing. degree and a Dr.-Ing. degree in Communications Engineering from the University Paderborn in 1991 and 1995, respectively. In 1996 he joined the Satellite Navigation department of MAN Technologie AG, Germany, where he was responsible for the architecture, digital signal and data processing of satellite navigation receiver systems. From 1999 to April 2002 he has served as the head and R&D manager of MAN Technologie's satellite navigation department. In May 2002 he joined IFEN GmbH, Germany, where he is currently the head of business development and R&D management.

Elmar Wittmann received a Dipl.-Ing. degree in surveying – major subject geodesy and satellite geodesy – in 2000 from the Munich University of Technology. He then joined the IfEN GmbH, where he is currently working as a project engineer in the field of GPS/Galileo satellite navigation at the Mobile Applications & Services department.

Rainer Kronberger is working in the Innovation, Standardization and Funded Project Department of Infineon Technologies AG in Munich Germany.

Christian Drewes is working in the area of 3G concept engineering for Infineon Technologies AG in Munich, Germany.

Timm Ostermann has received his MSc in Microelectronics from the Technical University of Hamburg-Harburg, Germany, in 1993 and his PhD from the University of Linz, Austria, in 1999. His PhD thesis was about characterization of SiGe MODFETs for use in circuit design. From 1994 to 2000 he was with the Department of Microelectronic Systems, Institute of Systems Science and from 2000 he is with the Institute of Integrated Circuits both at the University of Linz. He coordinates the analog and mixed analog-digital circuit design activities of the Institute. He is an expert in circuit simulation and modeling and has experiences in huge variety of CAD-Tools. Dr. Ostermann is author and co-author of over 40 papers in the field of device modeling, circuit simulation and analog and mixed-mode circuit design. Since Sept. 2000 Dr. Ostermann is deputy head of the institute.

Andreas Springer received the Dipl.-Ing. degree in Electrical Engineering from the Technical University of Vienna, Austria, in 1991, the Dr. techn. (Ph.D) degree and the Univ.-Doz. (Habilitation) degree both from the University of Linz, Austria, in 1996 and 2001, respectively. From 1991 to 1996 he was with the Microelectronics Institute, since 1997 he holds the position of an Assistant Professor at the Institute for Communications and Information Engineering both at the University of Linz, Austria, and since July 2002 he is head of this institute. His current research interests are focused on simulation of wireless communication systems, spread spectrum communications, single and multi-carrier communications, UWB, direct conversion architectures, equalization, MIMO, UMTS, and RFIC's. In these fields, he has published more than 90 papers in journals and at international conferences.

Linus Maurer received the Dipl.-Ing. Degree in physics and his Dr. techn. Degree from the University of Linz, Austria, in 1997 and 2001, respectively. Dr Maurer started his PhD in 1998 at the Siemens Semiconductor Division, Munich. From 1999 to 2001 he was research engineer at the Institute for Communications and Information Engineering. During this time Dr Maurer was engaged in the development of highly integrated UMTS compliant RF transceiver front ends in cooperation with Infineon Technologies. In 2002 Dr Maurer joined DICE, an Infineon Technologies design center, where he is responsible for forefront and funding projects. He received the ITG-award 2002 and the EEEfCOM award 2002. His main research interests are focused on the simulation of wireless communication systems with special emphasis on RF related signal impairments, CDMA system-engineering, SDR and mixed signal technology.

ABSTRACT

In the upcoming years the location of mobile phones or PDAs will become by far the market leader in the area of personal navigation applications. These trends converge in the U.S. Federal Communications Commission's E-911 mandate and the E-112 initiative of the European Commission that requires network carriers to provide location or geo-coding of emergency callers who are using wire-

less handsets. 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 receiver, which provides seamless indoor/outdoor navigation and communication capability, using GPS/Galileo and 3G/UMTS for mass market applications. The paper will present an overall overview of the GAWAIN project, its 3-step design approach and the architectural design. Preliminary results of analysis and architectural design of these concepts will be presented within the paper.

INTRODUCTION

Satellite-based navigation and positioning has already and will have an ever increasing influence on our daily life in the future. The recent signing of a cooperative agreement between the United State and the European Union (EU) on policies guiding the Global Positioning System and the Galileo system has laid the foundation for a compatible and interoperable Global Navigation Satellite System (GNSS). Modernization of GPS and completion of Galileo could produce within a decade a GNSS system of systems with as many as 60 satellites broadcasting several open civil signals that will probably be used nearly interoperably by future receivers.

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.

These trends are supported by the U.S. Federal Communications Commission's E-911 mandate that requires network carriers to provide location or geocoding of emergency callers who are using wireless handsets. Similar activities of the European Commission under the E-112 initiative have led to a regulatory directive in July 2003. Driven by such developments, interest in positioning techniques based on the use of a GNSS is growing rapidly in the consumer market community. Meanwhile, increasing demand for commercial location-based services (LBS) has driven cellular phone handset manufacturers and wireless carriers to focus on positioning solutions that are even more accurate than these regulatory mandates, opening new application markets with wide economic potential.

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 and its use of the V-engineering paradigm 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.

OBJECTIVES AND DEVELOPMENT APPROACH

The new demands to modern receivers are their very high flexibility to accept different signal structures, needed for navigation and communication under outdoor and indoor conditions. Today's high data rate communication services require high bandwidth signal processing capabilities. Therefore, the receiver must have also high processing performance. These two features may only be reached with the capability to completely configure the processor through software ('Software defined Radio') and the 'Reconfigurable Processor' (RCP) approach.

The core technical objectives of GAWAIN are:

- Development of an integrated GALILEO/GPS (mass market) prototype receiver, based on final GALILEO SIS ICD.
- Development of an UMTS prototype transceiver (with UMTS based positioning, provision of A-GNSS

data), according to latest 3GPP (Third Generation Partnership Project) release 6.

- Development of hybridized navigation solutions combining GNSS with UMTS navigation capability (with consideration of other systems like WLAN).
- Development of innovative transportation/tourism applications, using the integrated (mobile) GALILEO/GPS/UMTS prototype in combination with LBS data and maps.

As these developments are clearly ahead the current state-of-the-art, a three step development process consisting of a Software-Prototype (called Virtual Prototype), enabling end-to-end simulations and high flexibility in algorithmic design, a Baseband-(FPGA)-Prototype, with implemented Galileo/GPS/UMTS signal processing algorithms on a real signal processing device, and an Integrated-Prototype (GALILEO/GPS+UMTS including procured and suited RF-Front-ends and antennas), will be followed as shown in Figure 1, thus minimizing the development risks.

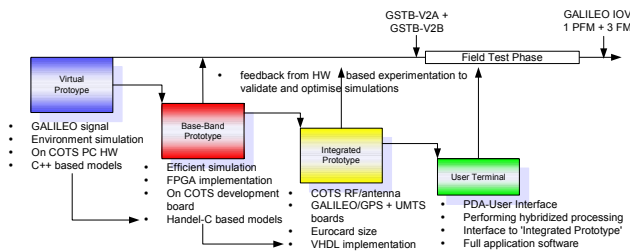


Figure 1: Development Approach of the GAWAIN Project

The project objectives are mainly driven by the current state-of-the-art in communication and navigation. Based on this state-of-the-art, the objectives of the project will clearly identify the add-ons beyond the state-of-the-art. All the core developments above shall create the necessary know-how, to come in a next (not part of this project) development step to a commercial product level, enabling full competitiveness on the different chip, receiver, mobile applications and services markets.

MARKET ASSESSMENT AND DEFINITION OF USER REQUIREMENTS

The project itself has been started with a detailed market analysis and the definition of the user requirements. Emphasis is put here on the intelligent transport and ubiquitous tourism market.

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 mar-

ket 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 (for cargo container and trailer applications) 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 communica-

tion standard UMTS will be briefly discussed within the next sections.

UMTS Signal Structures

Modulation Scheme

Figure 2 and Figure 3 show the spreading and modulation procedures for the DL-PCHs [1, 2]. Each pair of two consecutive bits is first serial-to-parallel converted and mapped to the I- and Q-branch. The I- and Q-branches are then spread to the chip rate by the same real-valued channelization code $C_{ch,SF,m}$. The sequences of real-valued chips on the I- and Q-branch are treated as a single complex-valued sequence of chips. The relative power of each complex-valued spread channel, corresponding to point S in Figure 2, is separately weighted by real valued gain factors G_i in Figure 3. All downlink physical channels are then combined using complex addition. The compound signal is scrambled (complex chip-wise multiplication) by the complex-valued scrambling code. Notice that the SCH channels are not subject to scrambling.

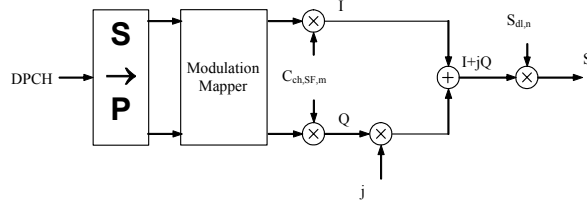


Figure 2: Spreading for all DL-PCHs except SCH

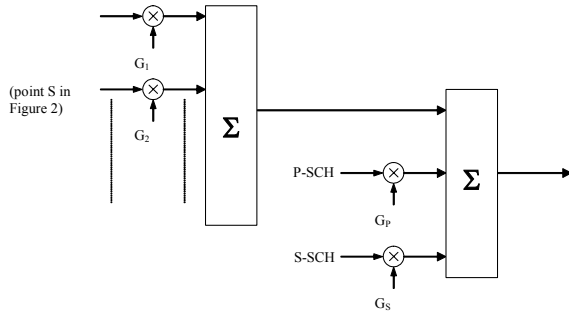


Figure 3: Combining of DL-PCHs

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 PAR can be derived from the Complementary Cumulative Distribution Function (CCDF) shown in Figure 4. 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 Figure 4 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.

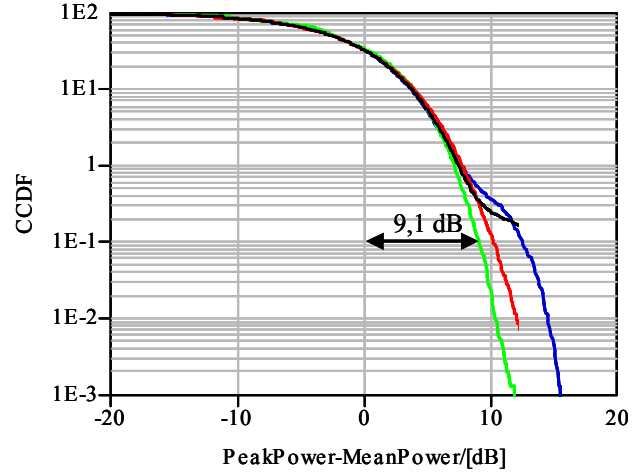


Figure 4: CCDF vs signal power of a DL-UMTS signal (CPICH, PCCPCH, PSCH, SSCH+3 DPDCHs (green), 9 DPDCHs (red), 17 DPDCHs (blue) and 25 DPDCHs (black))

Pulse Shaping

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 frequency response G_{rc} of the root-raised cosine (RRC)-filter with roll-off factor α , transition type n (RRC for $n=1$, raised cosine (RC) for $n=2$) and chip duration T_c is defined by

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

The pass-bandwidth of the above defined filter equals $(1+\alpha)/2T_c$, which results to 2.34 MHz for UMTS ($\alpha=0.22$, $T_c \approx 260$ ns). The impulse response for $n=1$ can be given as analytical expression, which is

$$g_{RRC}(t) = \frac{\sin\left(\pi(1-\alpha)\frac{t}{T_c}\right) + 4\alpha\frac{t}{T_c}\cos\left(\pi(1+\alpha)\frac{t}{T_c}\right)}{\pi\frac{t}{T_c}\left(1 - \left(4\alpha\frac{t}{T_c}\right)^2\right)}$$

Figure 5 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).

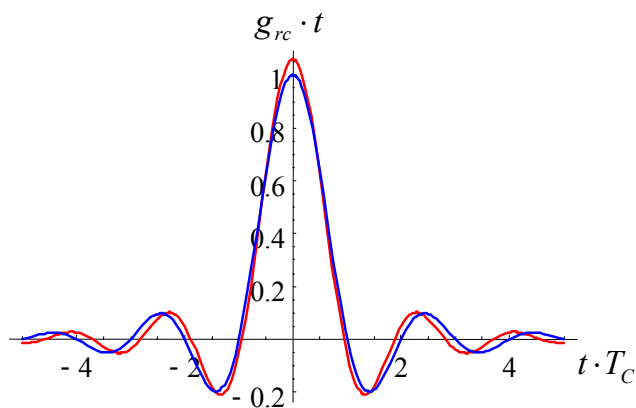


Figure 5: RRC (red) and RC (blue) impulse response.

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

Table 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. How-

ever, 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.

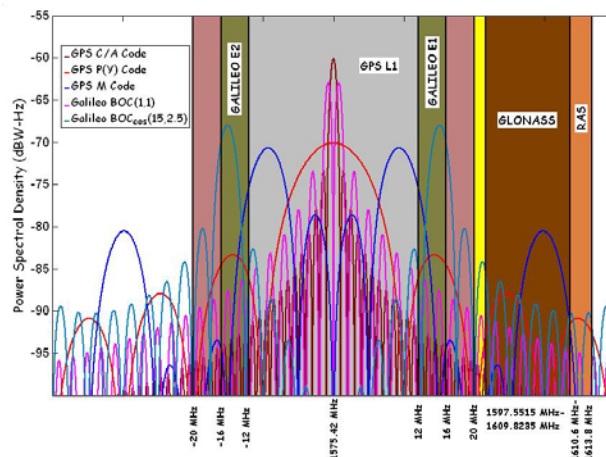


Figure 6: Galileo Frequency Spectrum

Figure 6 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 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].

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 (see Figure 7), low-IF and direct conversion receiver (DCR) depicted in Figure 8 [5]. The pre-dominant archi-

tures in current cellular RF front-end solutions use direct conversion between the RF frequency and baseband or a single intermediate frequency (IF). Architectures with multiple intermediate frequencies are rarely found these days.

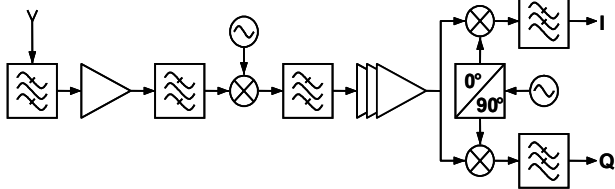


Figure 7: IF Receiver Architecture

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.

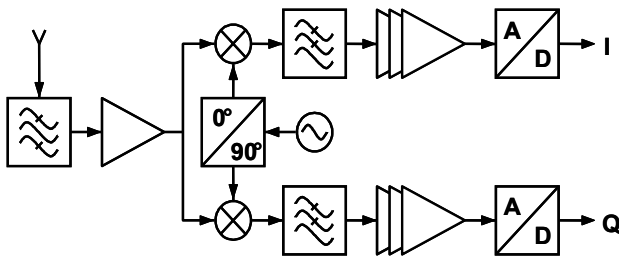


Figure 8: Direct Conversion Receiver Architecture

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 Figure 9). 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.

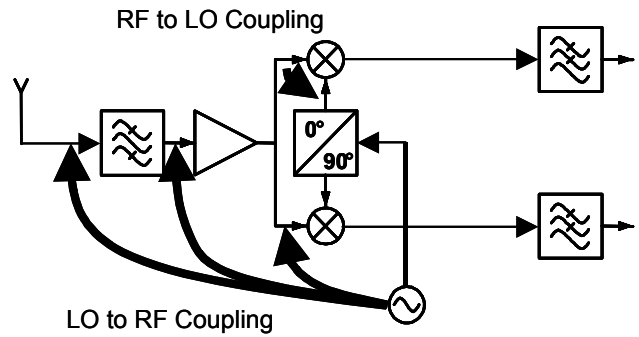


Figure 9: LO to RF and RF to LO coupling for DCR

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 Figure 10). 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 down-converted 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.

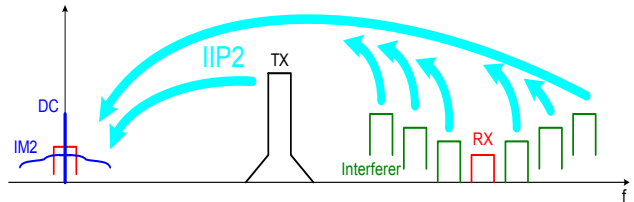


Figure 10: DC-offset generated by IQ-mixer IP2

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 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 (Figure 11):

- 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

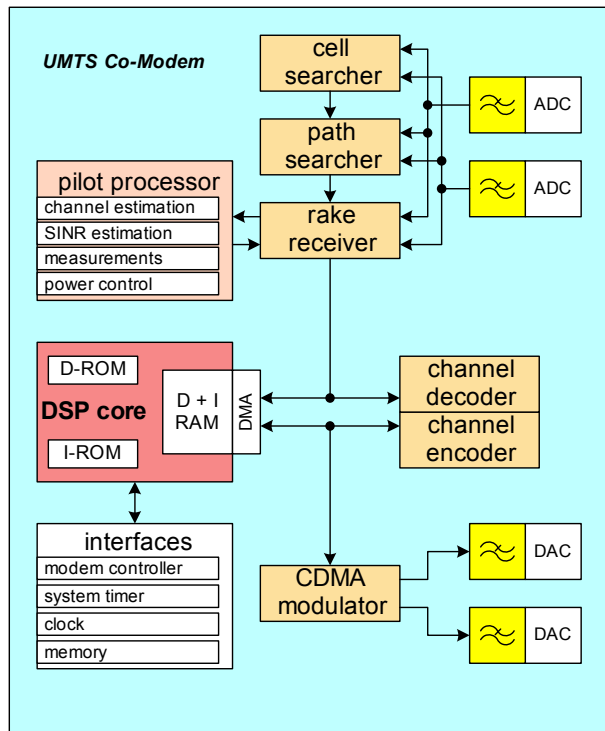


Figure 11: UMTS baseband co-processor architecture

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 Figure 12. 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.

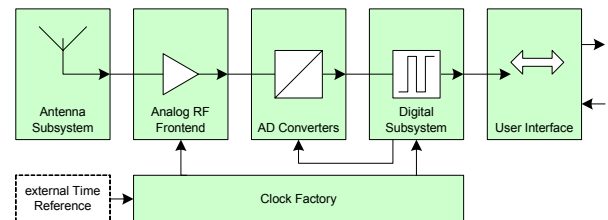


Figure 12: Hybrid Galileo/GPS Receiver Concept

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.

RF Front-End

For the combined Galileo/GPS receiver front-end a low-IF architecture is proposed as shown in Figure 13. This architecture comprises all benefits for a low-power, high-integration in complementary metallic oxide semiconductor (CMOS) technology while circumventing the problems of a DCR architecture described above. The bandwidth of the RF front-end is approximately 4 MHz, to include the two main lobes of the Galileo BOC(1,1) signal as well as the main lobe of the GPS C/A code with two side lobes.

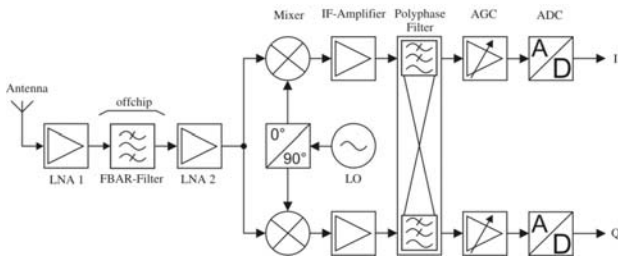


Figure 13: Low-IF Front-End Architecture

One major problem arises by the effect of self-mixing. The local oscillator (LO) and the LO-signal which is coupled into the RF cause a fluctuating DC-offset in the base-band. As the main slope of the GPS-signal lies around 0 Hz it would be severely degraded. The chosen low-IF architecture prevents this disadvantage by fixing the navigation signals at an IF of 3.5 MHz. Another advantage compared to the zero-IF topology is that the flicker noise between DC and 1 MHz is not a concern. Compared to a receiver with more than one mixer stage no further external filtering is required.

The limitation of the IF bandwidth is performed a poly-phase filter stage. The subsequent AGC further amplifies the signal to a detectable level and guarantees the optimal duty cycle of the three-bit ADC. A three-bit quantization reduces the SNR degradation to less then 0.7 dB. The target for implementation of the receiver front-end is an overall noise figure of 2 dB combined with low power consumption.

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 $F_s/4$ demodulator (F_s : sampling frequency) moving the signal frequency band down by a fixed unregulated value of a quarter of the sampling frequency, as shown in

Figure 14. 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.

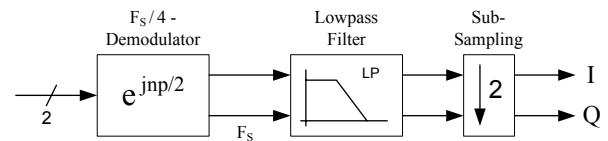


Figure 14: Digital Signal Conditioning

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 Figure 15. 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).

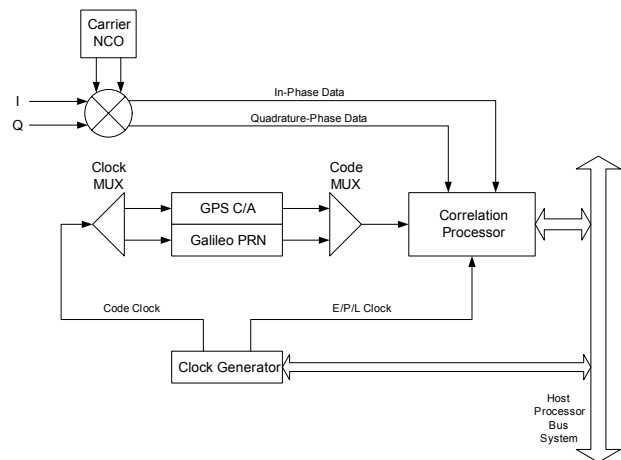


Figure 15: Despreading and Correlation Architecture

The same principle can be applied to the correlation processor for tracking mode, presented in Figure 16. 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.

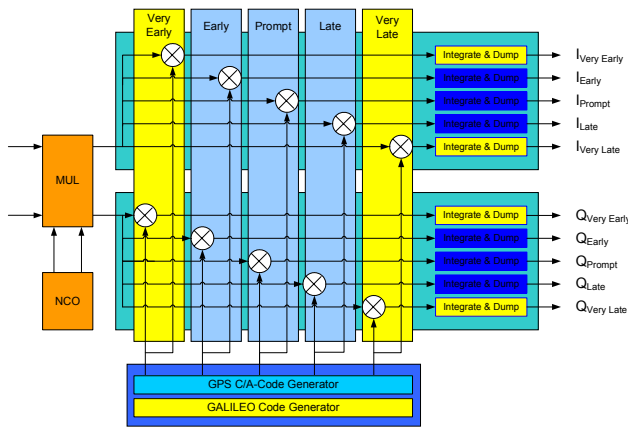


Figure 16: Combined Galileo/GPS Correlator Architecture

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 Figure 6. 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 following paired frequency bands:

Operating Band	UL Frequencies UE transmit, Node B receive	DL Frequencies UE receive, Node B transmit
I	1920 – 1980 MHz	2110 – 2170 MHz
II	1850 – 1910 MHz	1930 – 1990 MHz
III	1710 – 1785 MHz	1805 – 1880 MHz
IV	1710 – 1755 MHz	2110 – 2155 MHz
V	824 – 849 MHz	869 – 894 MHz
VI	830 – 840 MHz	875 – 885 MHz

Table 2: UTRA/FDD paired frequency bands

For the work within GAWAIN only operation in frequency band I is considered. The out of band emissions defined in [3] cover the frequency range from 2.5 MHz to 12.5 MHz away from the UE centre carrier frequency and,

therefore, are not relevant for interference to the Galileo/GPS receiver.

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 shown in Table 3 and Table 4 are only applicable for frequencies, which are greater than 12.5 MHz away from the UE centre carrier frequency.

Frequency Bandwidth	Measurement Bandwidth	Minimum requirement
$9 \text{ kHz} \leq f < 150 \text{ kHz}$	1 kHz	-36 dBm
$150 \text{ kHz} \leq f < 30 \text{ MHz}$	10 kHz	-36 dBm
$30 \text{ MHz} \leq f < 1000 \text{ MHz}$	100 kHz	-36 dBm
$1 \text{ GHz} \leq f < 12.75 \text{ GHz}$	1 MHz	-30 dBm

Table 3: General spurious emissions requirements

Operating Band	Frequency Bandwidth	Measurement Bandwidth	Minimum requirement
I	$875 \text{ MHz} \leq f \leq 885 \text{ MHz}$	3.84 MHz	-60 dBm
	$921 \text{ MHz} \leq f < 925 \text{ MHz}$	100 kHz	-60 dBm *
	$925 \text{ MHz} \leq f \leq 935 \text{ MHz}$	100 kHz	-67 dBm *
	$935 \text{ MHz} < f \leq 960 \text{ MHz}$	100 kHz	-79 dBm *
	$1805 \text{ MHz} \leq f \leq 1880 \text{ MHz}$	100 kHz	-71 dBm *
	$1893.5 \text{ MHz} < f < 1919.6 \text{ MHz}$	300 kHz	-41 dBm
	$2110 \text{ MHz} \leq f \leq 2170 \text{ MHz}$	3.84 MHz	-60 dBm
Note *	The measurements are made on frequencies which are integer multiples of 200 kHz. As exceptions, up to five measurements with a level up to the applicable general spurious emission requirements are permitted for each UARFCN used in the measurement		

Table 4: Additional spurious emissions requirements (operating band I only)

From this it follows, that an 3GPP compliant UE transmitter is allowed 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.

A further issue for the development of the GAWAIN prototype is the leakage of on-board RF emissions from the UMTS transmitter into the GPS/Galileo receiver. Based on the outcome of the above mentioned study appropriate measures have to be taken during the board design.

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 $s_1(t)$. The following Figure 17 explains this effect for an UMTS UE receiver, where $s_1(t)$ represents a strong signal on the channel adjacent the wanted receive signal. The yellow trace shows the spectral leakage effect into the wanted frequency band due to crossmodulation.

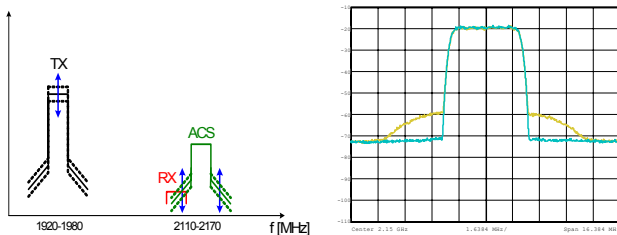


Figure 17: Crossmodulation (Shown here, for the case of an UMTS UE transceiver with a strong adjacent channel signal (ACS) which leaks via crossmodulation into the wanted receive band)

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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