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1. INTRODUCTION

1.1 Scope and General Logic

This document contains the Final Publishable Summary Report, section 4.1 of the Final Report. The content of chapters 2-6 of this document reflects the five sub sections in Final Publishable Summary Report Final Report in the FP7 Project management portal (https://ec.europa.eu/research/participants/portal/page/).

This document shall be a final publishable summary report covering results, conclusions and socio-economic impact of the project. It should be a self standing document carefully prepared.

This section will be edited by the Commission as such. The length of this part should not exceed **40 pages**. This report should address a wide audience, including the general public. This summary report has to be updated at the end of each reporting period.

2. Executive Summary

At the beginning of ART-X the commercial aspects were analyzed in WP 2000. Three main aspects were analyzed:

- The market situation for professional GNSS receivers
- Receiver IP evaluation: In view of the know-how available in the consortium the current IP situation was analyzed
- Business Case Analysis: The basic elements are the strategic plan, the marketing plan, the implementation plan and the financial plan.

The three components served as a basis to arrive at solid set of requirements for the professional receiver platform.

In parallel to the main development of the ART-X receiver platform new advanced technologies were analyzed in the WP 3000 series. The main topics were:

- Multipath real-time Detection and Mitigation
- Interference real-time Detection and Mitigation
- Difference Correlator for RTK
- Advanced Algorithms RTK Observables Processing
- Heading RF-Front-End
- Scintillation
- Advanced algorithms for 3rd-frequency ionosphere error correction
- Heading & Attitude determination capability

These WPs helped to further increase the level of know-how within the consortium. From some of these WPs IP filings were generated.

The main activity in the ART-X project was to develop a combined GPS/Galileo/GLONASS professional receiver prototype module with a clear perspective in an overall roadmap towards a solution presenting the best relation of all receivers in terms of functional flexibility/improved performance in relation to size/cost/power consumption.

For verification and testing purposes the commercially available NavX-NCS was updated to provide a dual antenna output. This was necessary to support the work done in the Heading and Attitude area.

The results outcome from WP 3000 (advanced technologies) as well as the ART-X prototype itself were implemented and tested during the project. In particular, the SX-NSR software receiver platform was used as a framework to verify and test the new advanced algorithms with real data.

3. Project Context and Main Objectives

The Galileo system will enable a tremendous performance improvement for professional applications, not only in terms of constellation, but especially due to the innovative signal definition (3 or 4 frequencies with high bandwidth and optimized CBOC signal). The latest advances in embedded processing gives rise to what is called here a `software concentrated´ approach for the development of Galileo/GPS and GLONASS prototype receiver.

The relationship between the results from ART-X and the overall objectives stated in the statement-of-work (project context) can be summarized as follows:

- *Increase EU competitiveness in the field of GNSS professional receivers*: The build-up of GNSS receiver know-how and implementation of a corresponding prototype within European industry that fits into a commercial roadmap. The corresponding test-systems (in particular constellation simulators) are very important, especially during the build-up phase of Galileo, this technology must be available from a EU only company.
- *Promote EU research and innovation in the future multi-system and multi-technology environment*: Developing advanced techniques in the field of GNSS processing, taking into account the future availability of multiple systems (Galileo, GPS, GLONASS, etc…). It was important to show the commercial relevance and users' benefits of these techniques.
- *Support Galileo penetration by exploiting the full potential of the Galileo signals (impact on Galileo community and market)*: Demonstration of the superior performance of the Galileo signals, in particular of the CBOC and AltBOC and providing a prototype able to utilize these signals is considered a valuable step towards convincing the users and the market in general to embrace Galileo.

An overview of the main project objectives is given below:

- Development of a combined GPS/Galileo/GLONASS professional receiver prototype module with a clear perspective in an overall roadmap towards a solution presenting the best relation of all receivers in terms of functional flexibility/improved performance in relation to size/cost/power consumption.
- As IFEN is involved in the EGNOS developments, the consortium is aware of the most important problems at reference station level: *Ionospheric scintillations, multipath and interference*. Therefore these issues will receive high attention within ART-X. It was important to address these issues in the frame of the advanced technology development.
- It is doubtful that it is currently possible to implement a completely software based (meaning software running on a processor, no FPGAs, no ASICs) multi-frequency professional Galileo/GPS/GLONASS receiver, targeted for the OEM market. However, the advances in low-power embedded processors may allow such a commercial implementation in the near future focusing on single- or dual-frequency solutions. This issue was implicitly addressed during the development of the advanced

technologies. Here all verification was implemented in a software receiver. Also the overall goal with the ART-X platform was to work towards a software concentrated receiver platform (or ASIC accelerated software receiver). An intermediate step towards this goal was achieved with the ART-X architecture. It is planned to replace the FPGA-part of the platform with ASICs in the future. The advantage of such an approach is the advanced technologies are more likely to be portable to such a platform than a conventional professional OEM system.

- Dual frequency measurements allow the elimination of the first order ionospheric error (the term proportional to $1/f^2$). Measurements on additional frequencies will allow higher order corrections. This may be useful in areas where the ionosphere is particularly violent (tropical regions). The higher order ionospheric corrections were analysed in the WP 3000 series (advanced technologies).
- Extending the `classical´ RTK approach to combined GPS/Galileo processing using RTCM 3.0 as a means for data exchange is an issue with great commercial relevance. It was a core objective to demonstrate the feasibility to implement a RTK solution directly on the ART-X platform. Thus, enabling an RTK solution that takes advantage of multi-frequency, multi-constellation signals.
- An innovative new RTK processing technique, called difference correlators and based on exchanging the correlator output values (instead of the usual observations) was developed, analysed, implemented and tested using the IFEN software receiver. It was a clear objective to demonstrate this not only using simulated data, but also using real signal in space. It was also important to demonstrate that the output of this advanced signal processing could be prepared and provided in such a format that it was possible to process the data using standard RTK methods. This approach was shown to yield much better performance than the classical observation-based approach, in particular under bad signal conditions.
- Development of an attitude/heading capable frontend for the SX-NSR software receiver. In order to demonstrate the heading/attitude algorithms a corresponding device producing the signal samples was necessary. The solution was to synchronize two NavPort 4 (NavPort 4 is a commercially available RF-Frontend from IFEN. It features four GNSS frequencies. The samples are made available to the SX-NSR via USB 2). This was achieved and the result is a software receiver based platform capable of providing attitude using four frequencies simultaneously.
- Attitude determination based on the same innovative principle (difference correlators). This principle was demonstrated and compared to the conventional approach. The availability was shown to be significantly better using the difference correlator technique between the two antennas. After the official closing of the corresponding WP, the robustness and availability was further improved by introducing vector tracking.
- In order to support the development of the attitude/heading algorithms, the NavX-NCS was extended to provide a dual RF output. It took considerable effort on both hardware and software side to successfully implement this additional feature.

4. Project Results

4.1 WP 2000: Commercial issues: Market analysis, IP analysis and Business Case development

The core objective of WP 2110 was to analyze the professional user market for GNSS receivers (step 1) and to derive a set of user requirements (step 2) based on the results of the professional user segment analysis. This document is the initial driver for all following ART-X prototype developments, as the technical requirements for the ART-X receiver will be derived from these user requirements.

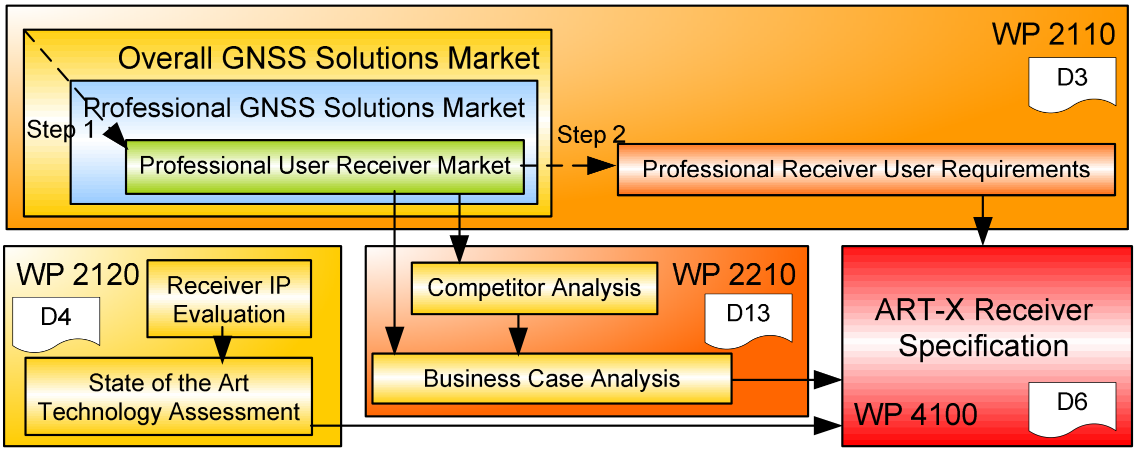


Figure 4-1: Overall approach for commercial analysis

The professional user segment analysis is the basic input for the competitor analysis and business case definition. Based on the business case definition and the generic user requirements, the final objective is to derive the ART-X receiver specification.

In WP 4100 'ART-X Technical Requirements' also the input from WP 2120 were considered, especially to avoid usage of protected patents.

4.1.1 Summary Market Analysis

The basic drivers for the coming generation of professional GNSS equipments are

- Combine ASIC benefits with necessary flexibility for coming systems and standards
- Support of 'All-in-View GNSS' capability (GPS, Galileo, GLONASS,…)
- Support for all types of HW interfaces for easy integration into application
- Support for easy local (MMI) and even more important for remote control (web based)
- Optimize continuous productivity (internal power supply and internal memory)

- Be prepared for all types of communication links as RTK requires message broadcast

The topics above are the more or less obvious drivers, which can be seen in all new OEM and receiver equipment being available in the next years. Minimize investment, optimize productivity and solve the wholly grail 'flexible AISC' are the final design drivers.

Today the 'professional GNSS' equipment is primarily signal processing focused, with RTK processing on the application processing side, also integrated into the ASIC. Now with the integration of NTRIP server also in the GNSS equipment, it seems that more an more application processing will be transferred into the 'GNSS chipset ASIC' to achieve a further cost reduction. However powerful SW processing inside an ASIC is not easy to achieve. Today it is enough to integrate 'cheap' embedded processing solutions into the ASIC's (e.g. LEON-3 license is starting at 50.000 € up to more than 100.000 €) with limited processing power.

However if in the future more processing power is necessary, it is necessary to license high-end application chips, being in the range of ~ 1 M€ licensing costs or even more. This would increase the barrier to develop new capable and flexible ASICs. But the need for more processing power is at the end driven by the applications requiring a complex 'application processing logic'.

Today one potential candidate is identified, which would require high end application processing power. This is the so called ADAS (automated driver assistance systems), which requires accuracies of ~ 10 cm (horizontal) in real-time, thus being a classical professional application). Furthermore ADAS also needs a complex application logic to meet the stringent and complex 'situation-awareness' requirements with high reliability (up to potentially high integrity requirements), which could be difficult to be achieved with classical ASICs application processing capability.

ADAS could be the first market where professional navigation accuracy is requested for a mass market segment (road/automotive). Due to the high volume and high integration level necessary, this could be also a driver to develop a dual-frequency L1/E1&L5/E5a RF-front-end ASICs, instead of the analog RF front-end chains used today in professional applications (determining to a high extent cost and size of current GNSS solutions). With this scenario also for the first time professional GNSS chipsets could be sold directly on the market, as it is typical for mass market.

Due to the continuously growing professional GNSS markets and perhaps some additional new professional markets, the professional GNSS market is a commercially very interesting market segment, suited for small to medium enterprises. But also this could change, if a mass market application would emerge.

4.1.2IP Analysis

In order to get along with the overwhelming amount of literature concerning all aspects of a GNSS receiver (RF technologies general and specific, baseband, CDMA, etc. this document will be structured such that a classification gives an overview over the relevant areas. The top level classes are divided in subclasses. For each subclass keywords are listed serving on the one hand as a nomination for the more specific areas inside a subclass and on the other hand as keywords for the research in the data bases.

Most relevant literature is summarized and all literature including more or less relevant literature is listed and rated.

It is highly remarked that the technologies mesh and a clear categorization is not possible.

4.1.2.1 Overview of Technology areas that are investigated

In a Navigation Receiver there are many technology areas beginning from the antenna over the RF Frontend, Baseband Circuits, Navigation Circuits, Interfaces, Power supply, common circuits as e.g. clock dispersion, software as well as all kind of mixtures and integrating of these technologies. For each of these technologies there exists countless patent- and non-patent literature with more or less relevance. Of course, relevant literature is not unconditionally stuck to Navigation Receivers. In this Technical Note the focus was primarily set on Baseband technologies and secondarily on RF Front End and Data Processing.

Note that a complete review and judgment of all available literature is not possible (neither Patent authorities claim this or their researches).

This chapter tries to give an overview in the form of a classification and sub-classifications of the technology areas investigated. It is unavoidable that some classes overlap.

The Top-Level classification is as follows

- Antenna
- RF Front End
- Baseband ("Baseband Processor")

The Baseband as the central part of a GNSS receiver is sub-divided into

- General Baseband Aspects
- Cross-correlation
- Multipath Mitigation
- Semi-codeless

4.1.2.2 Literature Sources

The main differentiation in literature is on the one hand the patent literature and on the other hand the non-patent literature. From aspect of IP professionals the patent literature is the main source. The patent literature is advantageous in

- scope of documentation
- quality of explanation and illustrations in sense of
- comprehensibility
- detailedness (contains illustrative embodiments)

- includes "side"-ideas

And last but not least in knowledge and handling of property rights.

4.1.2.3 Data Bases

The patent literature is searched via the data bases provided by the patent organizations over the internet. The data bases comprise all important states. The research is, however, restricted to English and German language (comprising thus also translations and translated summaries of Japanese and other patent applications).

As most companies are either located in the US or the US market is one of the most important many companies apply for a patent at the US Patent Office (USPTO). Thus, the main data base for this research was the USPTO data base, followed by the European Patent Office data base ESPACENET and the German Patent and Trade Office data base depatisnet http://depatisnet.dpma.de.

The non-patent literature comprises journals, proceedings, books and internet.

4.1.2.4 Conclusion IP Research

Lists with nearly 2000 patents have been created, sorted by companies. Independent from that patents and also literature mainly in the area baseband signal processing and antennae have been searched for. Only a small part of the researched patents could be investigated in more detail and it can't be stated that these ones are the most relevant ones. However, there are now comprehensive, clearly represented lists and it is recommended to keep an eye on the patents listed which are not covered in this document.

4.2 WP 3000: Advanced Technologies

4.2.1 Multipath Real-Time Detection and Mitigation

During this work package a partly optimized piece of C++ code has been developed to realize a multipath estimating discriminator. It has been tested with simulated GPS and Galileo L1/E1 signals and various multipath configurations. The benefits of these methods are intriguing and are:

- Multipath detection and mitigation capability
- Various applications: precise ranging, signal quality monitoring, scientific use (reflectometry)
- Generic approach suitable for all GNSS signal types
- High level of configurability

On contrast, it requires a significant computational load and – most importantly – the performance of the method depends to a large extent on the quality of the underlying frontend model.

It is clear that such a complex method needs to be parameter-optimized for different applications. To accomplish this task much experience with the application is necessary. Due to a lack of time, this optimization has not been performed in this WP. IFEN will apply this method for a reference receiver configuration in the very near future

4.2.2 Interference Real-Time Detection and Mitigation

Interference detection and mitigation techniques that may have an influence on GNSS signals have been stated in this study. Among GNSS signals, pulsed or CW interference signal effects on GIOVE E5a signal is specified and the methods indicated are tested with real and simulated E5a signals as well.

Since the method which outperforms others will be implemented on an FPGA platform, proposed method is weighted via computational complexity and performance.

As already mentioned, the ipexSR software receiver's front-end is not capable of performing real time domain blanking via AGC monitoring as for this front-end the gain factor is set externally by the user in dependence of the specific antenna to be used. Hence a continuous monitoring of the gain factor and steering the blanking already within the front-end is not possible.

As it has been shown the mitigation techniques have been applied to short double pulses that have been represented by DME pulses. For all interference power levels, in pulsed interference mitigation, using blanking method, interfering pulses are detected with higher precision with respect to DWT. Also considering highly computational requirement of Wavelet based method for a real-time process; against PI, pulse blanking or clipping and against CWI, notch filtering can be processed.

4.2.3 Scintillation Detection & Mitigation

In this document we discussed the research work undertaken for detection and mitigation techniques of ionospheric scintillation effect that is caused by ionization density irregularity in the 11 year period of solar activity. In strong ionospheric scintillation, the variation of GNSS signal amplitude may exceed 30 dB, and the GNSS signals become vulnerable with fatal consequences for the nominal operation of a GNSS Receiver.

Scintillation effect parameters: Two parameters were identified to represent scintillation effect. They are S4 index for amplitude scintillation, and σ_φ (sigma-phi) for phase scintillation.

Impacts on the signal processing of GNSS receivers: The code and Doppler tracking would not be strongly affected by scintillation effect because of their intrinsic robustness to the fading but the phase tracking could be problematic. The signal acquisition (or reacquisition) seems not to be problematic because most receives keep going to acquire the signal with redundant channels.

In order to monitor the scintillation effect efficiently, we need to use a receiver with a high gain antenna, a better oscillator, an AGC with a short time constant to decouple with signal amplitude fading, and baseband software modification. One of the possible solutions based on a cheap receiver is to modify the baseband software module to calculated S4 index.

Simulation of scintillation signals: Simulation of scintillation signals was performed in two levels. First, the ionospheric scintillation parameters were generated in global level using the GISM software. The generated scintillation parameters were used to see the scintillation effect in global level by showing scintillation maps. Second, the generated parameters in the first step were input to a single channel scintillated signal generator. The Cornell model, which is the complex signal generation scheme based on bivariate gamma random variables considering proper distributions, e.g., Nakagami-m for amplitudes and zero-man Gaussian for phases, was incorporated into the single channel scintillated signal generator.

Review on signal tracking loop and advanced signal processing technique based on Kalman filter: Basic theory and methodology of signal tracking loop were overviewed with a special emphasis on bandwidth setting depending on the user requirements. Signal tracking Kalman filter, which is known as one of the most advanced signal tracking technologies, was introduced in comparison with the traditional approach. A special note on the Kalman filter tuning method based on the empirical knowledge of equivalent noise bandwidth was discussed, so that the carrier phase jitter approximated from the measured C/N_0 could be used in the tuning of signal tracking Kalman filter in adaptive manner. This technique would be used to mitigate ionospheric scintillation effects.

In addition, clock oscillator and dynamic stress effects were analyzed with a special attention on the loop bandwidth and the pre-detection integration time. The high quality TCXO and the costly OCXO were assumed in the analysis, where they are expected to use in the ionospheric scintillation monitoring receivers in static mode.

Test and comparison of designed detection software: The scintillated signals generated by using the DLR model working on the Spirent simulator were used to test the designed monitoring software algorithm. The designed monitoring algorithm could detect the scintillation signals. However, the calculated S4 index values were little bit lower than the actual input. It is likely that this is because of uncertainty of scintillation signal model which is based on the Nakagami-m distribution.

On another hand, the use of the shorter pre-detection integration time of Galileo E1 provided the larger S4 values than the GPS L1. Therefore, this should be taken into account when the Galileo E1 receiver is used in the scintillation monitoring receiver.

For the purposes of this project a measurement campaign took place for two days from 29.07.2011 at Ouagadougou, Burkina Faso in Africa. The extensive analysis for the captured IF samples revealed that unfortunately strong scintillation effects were not observed well at the measurement campaign. In addition, the analysis of scintillation effect on L2/L5 bands seems problematic due to the strong RFI effect at the measurement site. This unexpected RFI effect may come from the nearby airport that should be installed with DME/TACAN systems transmitting high power pulsed signals. This effect may contaminate the measured signals so that the scintillation effect analysis became more difficult.

4.2.4 3rd-frequency Ionosphere Error Correction

The main purpose of WP is 1) reviewing of ionosphere correction algorithm based on triple-frequency approach, 2) designing of ionosphere correction algorithm in consideration of 1^{st}, 2^{nd} and higher order ionosphere error terms, 3) its implementation and evaluation by post processing and real-time. Work list accomplishing relating to WP, are as follows.

Developing algorithm in WP is evaluated by post processing and real time operation. Its estimate outputs are compared by Klobuchar model estimates and its estimates of GPS and Galileo. Through this approach, algorithm's feasibility and reliability is proven in theoretical basis. However, all evaluation is based on quantitative analysis since there isn't benchmark and it is not possible to acquire position estimates because of lack of available triple-frequency satellites.

Although range comparison method in above is enough to evaluate this approach, we agree that another evaluation based on positioning and comparison with the accurate benchmark parameters except for Klobuchar and NeQuick, seems to be needed. When launching GNSS FOC, it is possible to evaluate again through more concrete benchmark and positioning estimates.

4.2.5 Difference Correlator for RTK

A difference correlator module has been developed for the SX-NSR. Procedures are available to record data and to post-process them. For different applications (static indoor, forest, pedestrian, slowly moving indoor) parameter sets have been identified, which provide an optimum result.

The module has been verified by a large number of tests and we are confident that it has been implemented correctly. Tests under good signal conditions reveal an identical performance as classical PLL tracking.

For the forest environment, the walking pedestrian and the static indoor environment we find that signal processing and subsequent positioning gives consistent results. The difference correlator allows to track the carrier phase in an unprecedented stable way and even for an indoor environment continuous carrier phase estimates are available. The difference correlator drastically improves if integration times of > 5 – 30 s are used. Then the frequency selectivity gets quite high, thereby removing multipath. Our maximum integration time was 30 s, but this was chosen just for convenience. Further experiments with much longer integration times up to a few hundreds of second are imaginable.

Long integration times can currently only be achieved for static applications. For the pedestrian walk we were limited to 250 ms and for the slowly moving indoor test to 2 s. Longer integration times for moving platforms can be achieved only by precise (mm to cm-accurate) aiding with inertial sensors or dead reckoning algorithms. This is not considered in the ART-X project.

The ability to track the carrier phase in degraded environments gives us precise carrier phase pseudorange measurements. The measurement accuracy is intrinsically at mm- to cm-level. Those measurements are however influenced by remaining multipath effects or refractivity biases due to vegetation or building materials. Both induce ranging errors, which the positioning filter has to cope with. They are substantially larger than for free line-of-sight conditions and present a significant problem when using the observations.

The slowly moving indoor test did not show the expected behavior. Moving the antenna back and forward resulted in a large number of cycle-slips although the available signal power was sufficient to track the phase. Here further investigations would be needed and a better experimental setup should be designed.

It would be advantageous to do more comparisons against commercial RTK systems to demonstrate the benefits of the difference correlator for various applications. Dual frequency operations can be achieved with L1C/A and L2CM. Up to five satellites are already simultaneously visible for a few hours per day.

4.2.6 Heading and Attitude Determination Capability

An attitude determination algorithm has been implemented in the SX-NSR together with an attitude single difference correlator. It will serve as a generic default implementation in the product without any specific application in mind. It is a generic (multi-frequency, multi-GNSS) approach working on an epoch-per-epoch basis. Its immediate purpose is to serve as testing tool for the NavPort-4 dual-frontend, and the NavX-NCS signal generator.

The ambiguity resolution method itself is based on the LAMBDA method and seems to be able to fix ambiguities within a single epoch. It is absolutely essential that the ambiguities are decorrelated using the Z-transform before fixing. Prior test without using the decorrelation showed a much worse performance. Carrier smoothing can be applied to further increase the code ranging accuracy. From our tests, we conclude however, that also unsmoothed pseudoranges allow fixing the ambiguities within one epoch. This is probably due to the fact that only thermal noise is simulated. Tests in real environments will show, if smoothing is a proper measure to reduce multipath. Often, only one ambiguity set fulfills the baseline length constraint.

The overall standard deviations for the processing settings used are in x, y, z: 1.03 mm, 0.57 mm, 1.2 mm. That corresponds to the expected noise level of the carrier phase observations.

Further test with the NavX-NCS and the dual-frontend SX-NSR will be done in WP6200 and will be documented in 'Receiver Test Report D10'. Tests with the single-difference correlator are expected to demonstrate its performance benefits in real environments

4.3 WP 4000: The ART-X Platform

The primary objective with the ART-X platform is to address the short term market opportunities, listed in section 2 of [PL]. This is to address the augmentation reference receiver market. In the following sub-sections the various sub-systems of the receiver are justified in this sense.

A second objective with the ART-X platform design is to serve as a fore-runner of an ASIC based OEM module. This is reflected in the mid-term marketing of an OEM module, explained in chapter 2 of [PL]. Therefore it is important to map the architecture the ART-X platform to the planned OEM module.

In particular, the hardware/software partitioning is reflected in the ART-X platform. The digital signal conditioning is designed as part of the main board. The high-speed base-band processing is contained in separate FPGA based modules (see base-band processor in subsequent chapter). The digital logic implemented in the digital signal conditioning as well as the base-band processors will become parts of the digital ASIC. Thus, the digital signal conditioning and the base-band processors map into the ASIC, including internal and external interfaces.

The ART-X platform is equipped with a so-called system on a module, containing an ARM Cortex A8 processor. The logical interface between the base-band processors and the CPUs is the one foreseen for the OEM module. It is planned to use an OMAP processor on the OEM module as well (perhaps a newer generation). The envisaged OEM module would contain the OMAP processor, directly on the PCB. However, all logical and physical interfaces would remain the same (except for connectors and the PCB itself).

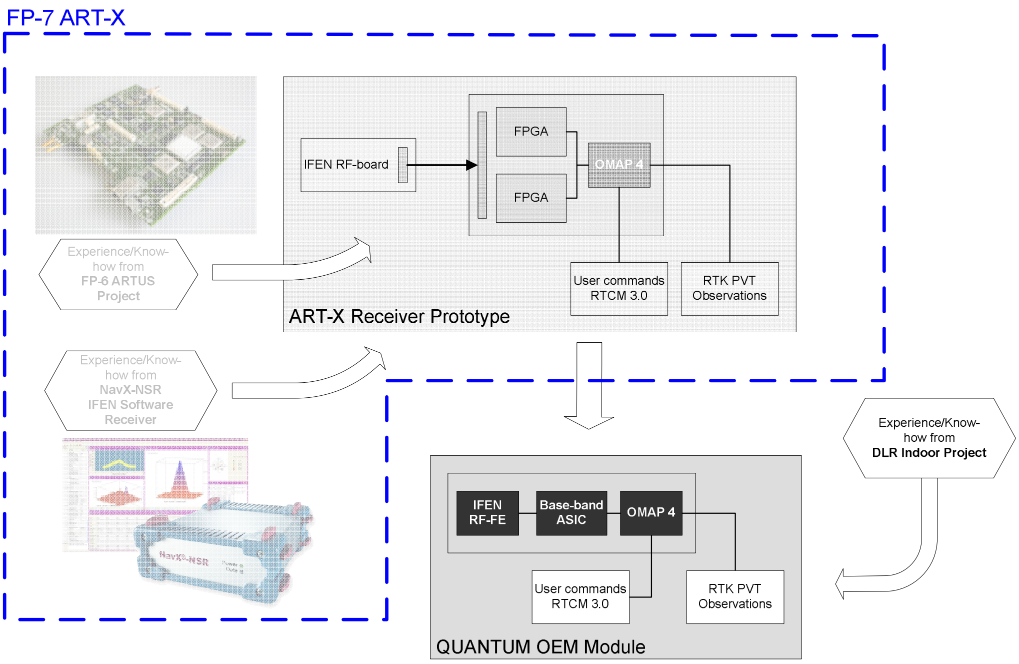


Figure 2: Technical relationship between the planned OEM module and ART-X

To better understand the link between the ART-X platform and the planned OEM module the main design ideas are shown below. The core features of the planned module can be summarized as follows:

- Four [TBD] frequencies that can be used *simultaneously*.
- Flexibility in frequency configuration: To a certain extent it shall be possible to configure the module to (almost) any frequency made available by any GNSS.
- Attitude determination: Four RF front-ends support attitude determination on two frequencies

- E6 capability: Galileo foresees code-encryption on E6. The spreading code encoders will be embedded within the ASIC as well as a flexible interface to support on-the-fly key change. Further up-stream processing is implemented in software; hence any data decryption / key-handling algorithm can be anticipated.
- Flexible channel structure: SC3 (patent pending). Supports 'all' signals: Galileo (including CBOC, AltBOC and coherent/non-coherent combined tracking of data and pilot, see later sections), GPS (including L1C TMBOC), QZSS, Compass
- Overall power-budget 3 W

The figure above shows the relation between planned OEM module and ART-X. The three major challenges in the OEM design will be:

- ASIC Implementation: transfer the functionality implemented in the FPGAs to an ASIC. The ASIC is necessary to be able to process all the Galileo/GPS signals for an all-in-view scenario.
- Efficient RF-section: In order to meet the requirements in size and power consumption, it is considered necessary to implement the RF section using RF ASICs
- OEM Module design: Small and power-efficient PCB, with an OMAP 4 application processor

The volume (number of units sold) defined by the professional market does not allow for the use of the latest IC technology in the dedicated chips. Typically, the integrated digital base-band processors use a technology, which lags two or three generations behind the current technology in embedded processors. For example, the latest integrated base-band processors are typically implemented in a 90 nm process, while the current embedded processors are implemented in 45 nm technology. This difference alone implies a tremendous boost in performance and power consumption. Also modern embedded processors implement a multitude of interfaces that are readily available.

An overview of the OEM module is shown in the figure below. The main components are:

- Four frequency RF sections, optionally with two RF inputs for attitude
- Base-band ASIC
- OMAP-4 Application processor
- Clock synthesis

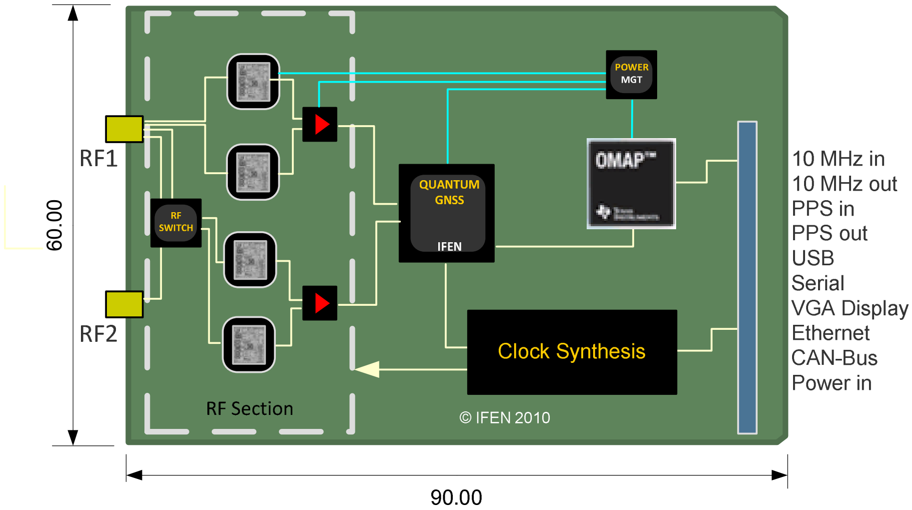


Figure 3: Overview of the QUANTUM OEM module

The decision to use an external CPU as opposed to integrate it into the ASIC has several reasons:

- High FLOP/watt ratio: As already explained the available processors are produced in the latest technology, not accessible to the ASIC production
- Flexibility: The life cycle of an ASIC is relatively long. However, the module as a whole typically has a shorter life cycle. The possibility to replace the processor when newer, faster and more power efficient ones become available is an advantage.
- Large feature-set: The OMAP processor features a series of interfaces (serial, Ethernet, video, USB, Bluetooth, CAN, etc). Having those available enables us to provide these interfaces to the customer as well.

4.4 WP 5000: AIV Tools – Signal Generator Update

The section on the signal generator is somewhat more detailed than other sections. This is justified as there was no project documentation on these activities.

The main objective of the activities covered by WP 5000 was to provide a test platform for the attitude capability of the ART-X receiver. For this purpose, the existing NavX-NCS system has been modified and equipped with a second RF output (see Figure 4-4).

Figure 4-4: ART-X signal generator with 2 RF outputs

The necessary system modifications covered both the signal generator hardware and the steering software and are described in more detail in sections 4.4.1and 4.4.2. The activities related to system integration and system testing are covered by section 4.4.3.

4.4.1 WP 5310 Signal Generator HW MAIT

In summary, the following HW modifications/activities have been carried out:

- Development of a signal generator with 4 HW modules (à 12 channels) and 2 RF outputs based on the existing architecture of the NavX-NCS. For this ART-X signal generator, the module-to-RF-output assignment has been chosen such that modules #1 and #2 are connected to RF#1, and modules #3 and #4 are connected to RF#2. This architecture allows the simulation of 2 single-frequency users with 24 channels available for each user or the simulation 2 dual frequency users with 12 channels available per user and frequency band.
- Implementation of firmware modifications to support the new multi RF capability, to ensure correct code- and carrier-phase relations and to minimize inter-module biases.

All hardware modules (reference board, rf synthesizer, high precision oscillator and rf combiner) were completed end tested extensively. The tests and the necessary modifications of the modules were finished in September 2011. All the modules showed the expected performance. As an example the phase noise of the synthesizer (layout in figure 2-1) is shown in figure 2-2. An outstanding signal quality can be observed, which ensures an exceptional low jitter.

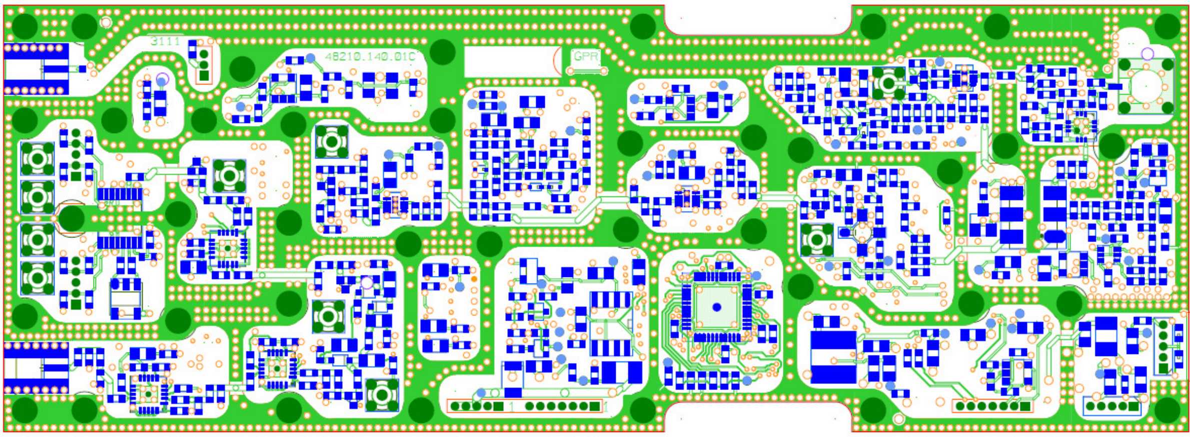


Figure 4-5: RF Synthesizer Board PCB

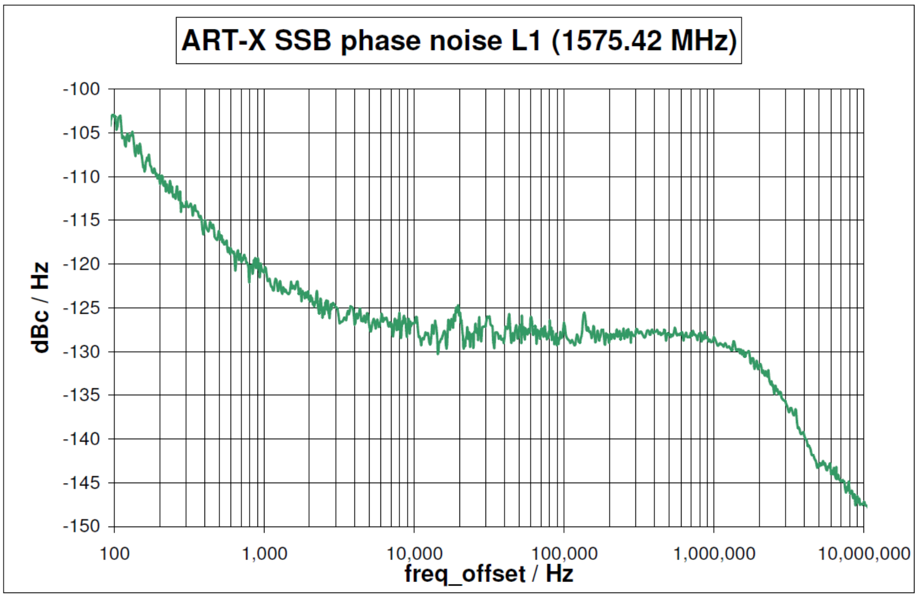


Figure 4-6: Phase Noise of the new synthesizer

As the most important test for the ART-X application on module level the phase difference between two boards was monitored while changing the temperature of one or both modules. In the range of 10°C to 55° C the phase tracking was better than 2° when both modules were kept on the same temperature. Even with one module held on a constant temperature the tracking was better 5° over the whole range. The tests were performed using the E1 frequency 1575.42 MHz.

All tests on module level were carried out successfully. As usual some modifications and improvements had to be implemented before fulfilling the target specifications.

4.4.2 WP 5310 Signal Generator SW MAIT

The existing NCS Control Center SW has been used as a basis to implement all SW modifications necessary to support a signal generator with 2 RF outputs. The NCS Control Center SW mainly consists of three architectural parts, namely the user interface (GUI), the GSPF middleware, which is responsible for conducting the simulation processing itself, and a so-called "configuration builder" which translates the settings made by user in the GUI into an executable GSPF configuration. When implementing new functionality, the corresponding modifications typically have to be implemented in all three architectural parts.

The following SW modifications were necessary to **support 2 RF outputs**:

- Handling of two different user positions / antenna locations under the assumption that one antenna location is fixed – thus serving as "reference station" – and the other can either be fixed or follow a user-defined trajectory.
- Adapt channel selection approaches to ensure that the two sets of signals (as received by antenna #1 and #2) are assigned correctly to the corresponding RF boards.
- Add new modules in GSPF middleware to ensure correct handling of a second user
- Modifications of user interface (NCS Control Center)
    - Implement missing configuration options
    - Implement monitoring options
    - Display of HW-related information (e.g. no of RF outputs)
- Implementation of SW/HW interface modifications (this is related to communication between the SW and the HW - and vice versa)

The following software modifications were necessary to simulate **vehicle attitude**:

- Implementation of motion model (computation of roll/pitch/yaw angles) for land vehicles. A simplified motion model has been implemented, where the roll angle is always zero and no backward motion is supported.
- Implementation of motion model (computation of roll/pitch/yaw angles) for aeroplanes based on plane characteristics like weight, wing area, liftoff and travel velocity.
- Display of monitoring information for vehicle attitude by
    - Displaying numerical values for roll, pitch and yaw in the monitoring tree or in the form of a special monitoring widget in the NCS Control Center
    - Exporting the trajectory simulation data (including attitude) to Google Earth and displaying it via 3D vehicle models
    - Using the artificial horizon, a new monitoring widget, which is part of the NCS Control Center software

WP 5000 also contained activities to implement software modifications to allow **complex multipath simulations**. This included the implementation of a function to import multipath data from file (as generated by the in-house ray tracing SW) and the visualization of the simulated multipath rays using Google Earth (see Figure 4-7). The ray tracing SW is used for the following preprocessing steps:

- Compute all occurring reflections on the basis of a predefined user trajectory, a satellite constellation and a 3D city model including material characteristics
- Generate a multipath file, which contains information about the multipath conditions at each point in time. This includes the no. of multipath signals, path delays, Doppler offsets, attenuations or signal types (e.g. LOS, reflection, refraction, transmission). This file can be imported by the NCS Control Center to “replay” the contained multipath information.
- Generate a file containing the coordinates of the reflection points for each signal path. This allows the visualization of the multipath environment in Google Earth as illustrated in Figure 4-7.

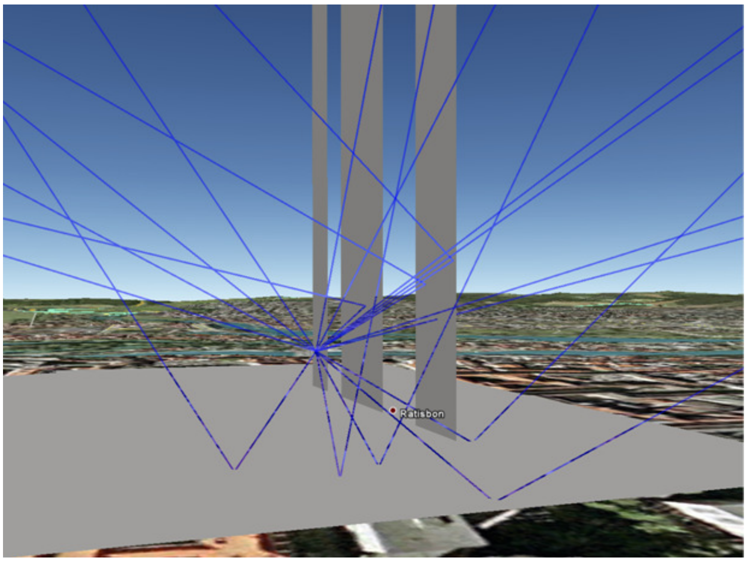


Figure 4-7: ART-X signal generator with 2 RF outputs

Limitations of this approach are:

- The ray tracing SW is a stand-alone tool and not integrated into the NCS Control Center software. As a result, the multipath information has to be generated externally during a preprocessing step.
- The ray tracing software is not real time capable, i.e. it takes some time to preprocess the multipath information.

4.4.3 WP 5330 Signal Generator Integration & Test

Integration tests. Using the new modules, a prototype simulator was built with four rf chains and two 2 to 1 combiners the simulator has two independent outputs (see Figure 4-4). The new rf boards were combined with the available NavX 12 channel baseband modules. The ART-X prototype was at first undergoing tests to verify the hardware as a system.

The following integration tests were made:

- Compatibility
  The new hardware was operated using the normal Nav-X software. The simulation was monitored with a spectrum analyzer and a navigation receiver. No difference to the old NavX design could be observed.
- Removal of ambiguities in code and carrier phase
  Due to the new synchronizing circuit all the modules come up now with a well defined code and carrier phase. This is the case after power up as well as after reprogramming the modules.
- Steering of code and carrier phase
  Using a low level control software, a defined phase offset was set between two modules. The differences between code and carrier phases were verified using high speed oscilloscope and network analyzer.
  A special case is to generate two signals with equal shape and amplitude but with a carrier phase difference of 180°. When adding such signals in the combiner a complete cancellation takes place in the ideal case. In reality the strength of the residual signal allows to estimate amplitude and phase accuracy.

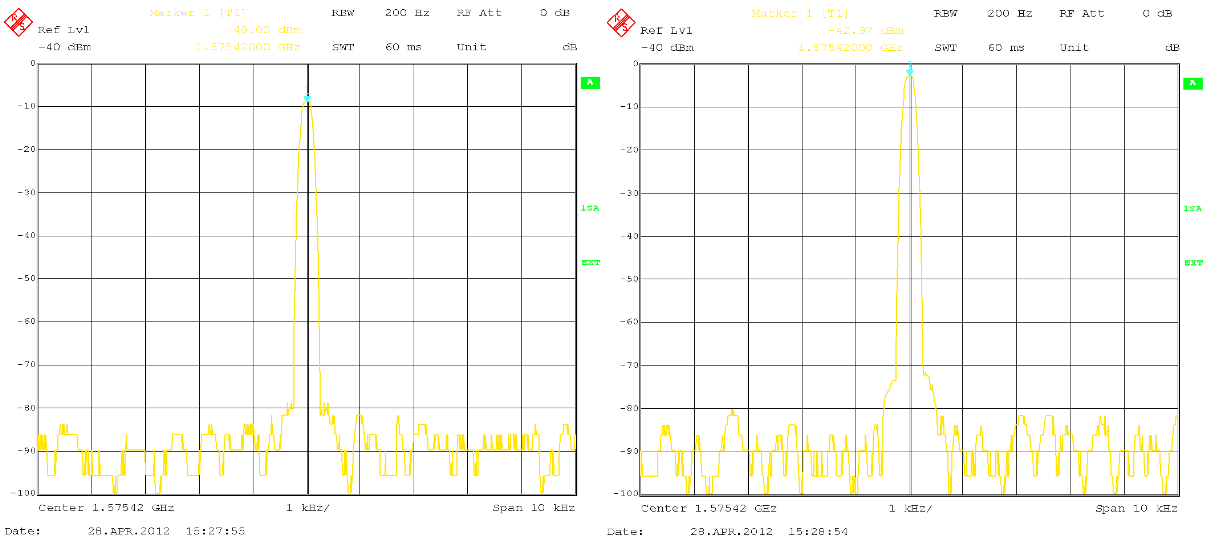


Figure 4-8: CW at one card only, and at two cards simultaneously (increase of 6.02 dB)

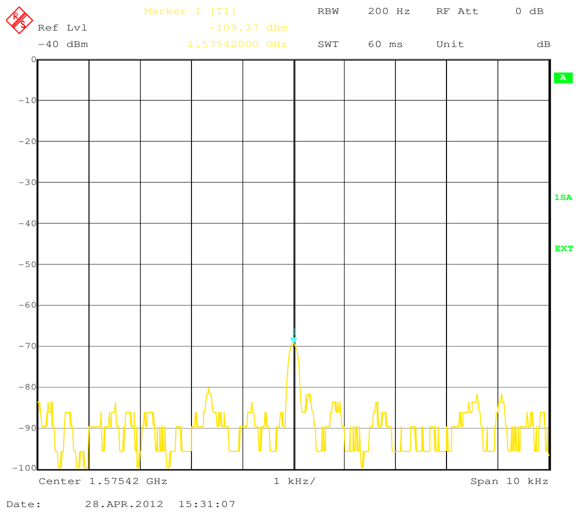


Figure 4-9: Phase-inverted CWs with resulting cancellation and small residual signal

End-to-end tests. Finally, the ART-X signal generator has been tested and verified by performing end-to-end system tests with commercial GNSS receivers (NovAtel Beeline and SX-NSR), which have 2 RF inputs and are capable to determine heading information.

One example for such a test is illustrated in Figure 4-10. In this test, the NCS was configured to simulate a static reference position and a static user position. The locations of the user were chosen such that different heading angles (angle between North and the baseline between the user and the reference station) could be realized. The simulated heading angles were 180°, 270° and 45°, respectively, using rather short baselines. Figure 4-10 shows that the connected NovAtel Beeline receiver was able to determine these angles (see right-hand instrument view extracted from the Beeline's user interface).

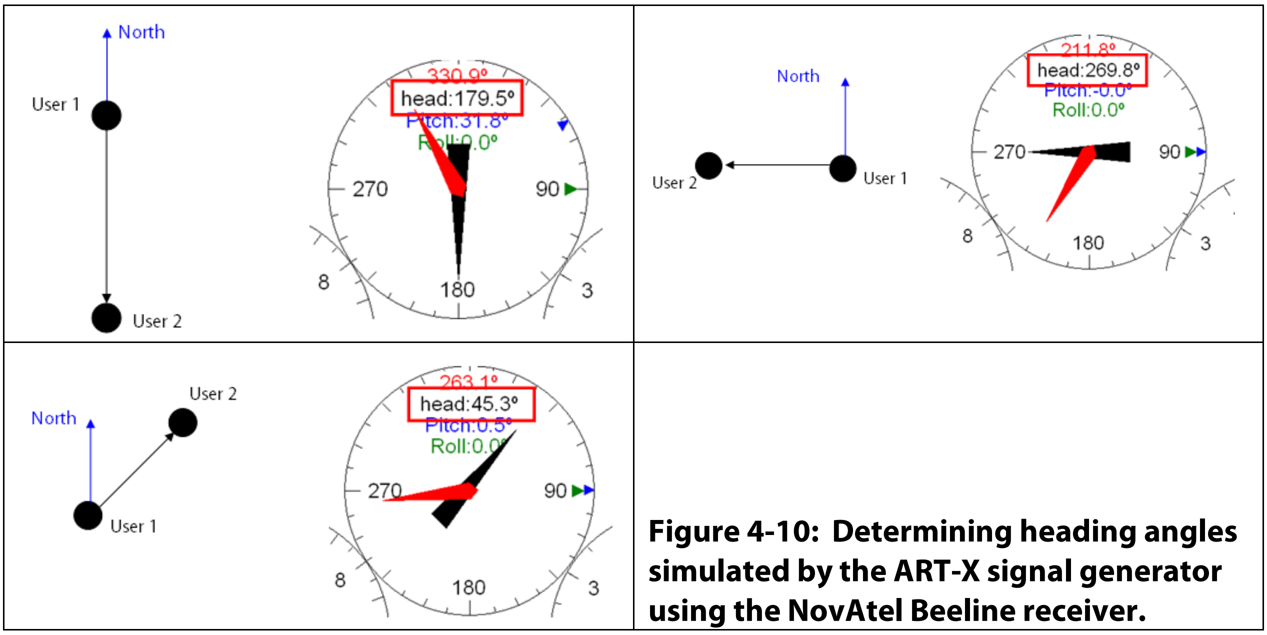


Figure 4-10: Determining heading angles simulated by the ART-X signal generator using the NovAtel Beeline receiver.

Another test that has been conducted to verify that the phase relations between the two RF outputs are simulated correctly is to analyze the phase observations recorded by the receiver. Again, the simulated scenario contains a static reference stations and a static user, separated by a baseline of 2m. After forming double differenced phase observations and removing the geometry, the resulting time series must be parallel to the x-axis (no ramps and drifts), the y-values must coincide with an integer number of cycles and the difference between time series for different satellites must be *n* cycles. As Figure 4-11 indicates, the phase observations obtained from the ART-X signal generator show such a behavior.

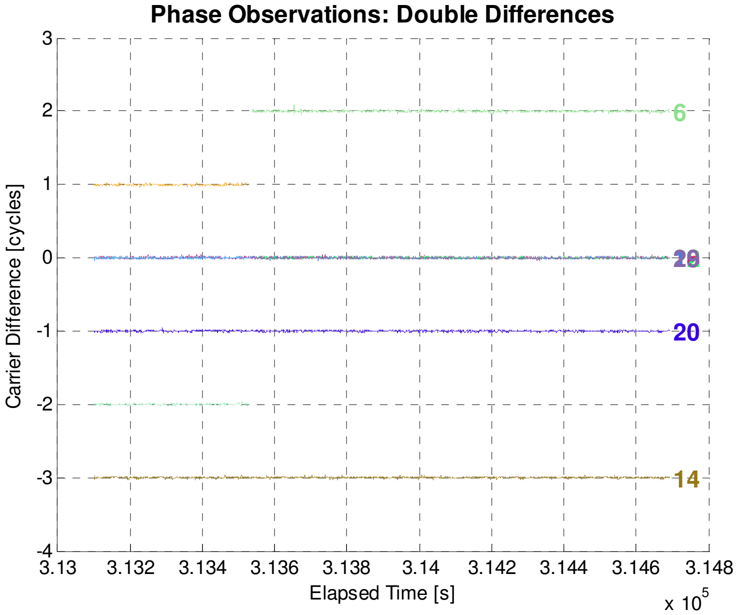


Figure 4-11: Double difference analysis of phase observations obtained from the ART-X signal generator.

4.4.4 Overall Status

The signal simulator activities conducted in the frame of the ART-X resulted in the development of a well-functioning prototype signal generator equipped with 2 RF outputs, which fulfills all requirements that have been defined for this system. However, the system still requires some SW modifications to become a sophisticated and easy-to-use product and finally to achieve market readiness. Especially in the field of user interaction / usability / configurability, further improvements will have to be implemented before the system can be shipped to the first customers.

4.5 WP 6000: Trials and Results Validation

4.5.1 ART-X Advanced Algorithm Results

This chapter includes a summary of the results from the advanced algorithm WP 3000. The use of the algorithm in the hardware receiver platform and the software receiver concludes each section.

WP 3110 Multipath Mitigation: The developed multipath mitigation and estimation scheme uses multiple correlators to estimate line-of-sight and multipath propagation parameters. It has been tested for up to 3 propagation paths. The C++ algorithms are operational and allow real-time operation on a PC platform. Efficient matrix operations and correlation function interpolation are hot spots that need to be optimized before porting the code to an embedded platform. The calibration efforts to obtain a precise model of the correlation function are significant. This issue is currently solved by a trial-and-error approach based on manually tuning correlation function parameters. The algorithm is used in the software receiver for better multipath mitigation and more importantly to estimate channel properties and to analyze signals for GNSS reflectometry.

WP 3120 Interference Mitigation: The work package includes an overview of the most important interfering signals. Their understanding is important to assess the possible and need and use of a mitigation scheme inside a receiver. For pulsed signals, a blanking/clipping scheme, a STFT with FCME scheme and wavelet techniques have been considered. Tone interferer have been detected and mitigated in the frequency domain via clipping, or have been mitigation in the time domain via notch filters. The selection of the optimum technique is application and platform dependent. An excellent library of C and C+ code is now available to IFEN and can be used if there is a specific demand. At the moment, pulse blanking and clipping is used in the operational IFEN receivers.

WP 3130 Scintillation: The work package discussed in detail the phenomenon of ionosphere scintillations, their impact on a GNSS receiver and how different GNSS signals are affected by them. Extensive scintillation data was generated by a software simulator, an RF simulator and during a measurement campaign. An optimum Kalman filter based tracking scheme has been implemented as well as a scintillation parameter estimator. The estimator was verified with the RF simulator successfully. Important practical experience was gained during the measurement campaign, but no strong scintillation could be covered. The tracking loop scheme and the estimators will make their way into operational IFEN receivers during the next time. The computational load of the algorithm is low.

WP 3130 3rd Order Ionospheric Delay: The impact and origin of the ionospheric delay has been discussed with the emphasis on the 2nd order ionospheric term. This term can be estimated, if more than 2 frequencies are observed. Various models and estimation techniques have been discussed. They can be easily implemented the software or hardware receiver, as they work at the observation level. 2nd order ionospheric delays have been estimated using real-world GPS and Galileo code and carrier pseudoranges. Its estimation can be used as an additional observable to monitor e.g. the performance of a reference station. So far no practical need to include the estimation in a positioning algorithm has been identified.

WP 3210 Difference Correlator: The difference correlator concept was discussed and tested extensively for RTK positioning and attitude. Difference correlators for attitude are part of the operational IFEN software receiver and might also find their application for GNSS reflectometry. The computational load is low and can be straight forwardly be implemented in the ART-X hardware platform. Tests using real data for car attitude determination showed a significant increase in the availability of a precise attitude solution, when using difference correlators. Also the RTK tests showed a strong availability increase of carrier phase observations even indoors. Those observations are often degraded by increased multipath and propagation delay variations making it necessary to redesign well known RTK/attitude algorithms. Those algorithms originally rely on a carrier phase accuracy of a few mm (to fix the ambiguities) and should be adapted to work with an accuracy of a few cm.

WP 3230 Attitude Determination: A single epoch attitude determination algorithm has been implemented in C++. Making of use of the LAMBDA method, it decorrelates carrier phase ambiguities even for multiple frequencies and systems. Tests have been performed for GPS C/A and Galileo E1 with RF simulated signals and real signals. For a baseline of 25 m and clean signals, an attitude accuracy of 0.002° was obtained; real world tests on a car with a baseline of 2.88 m showed an accuracy of 0.1 – 0.2°. The ambiguity search space is typically quite large (and a large computational load is necessary to search it) as only one epoch of carrier phase observations is used. On the other hand, errors due to cycle slips or wrong ambiguity fixing affect only one epoch. Carrier smoothing of the code observations (eventually based on the single difference correlator phase estimate) shrinks the search space. Further improvements would be expected from a Kalman filter based determination.

Conclusions: All the mentioned five WP3000 topics cover advanced GNSS signal processing or navigation topics. In each work package significant results have been achieved and in all work packages real-world data has been used to verify the algorithms (at least briefly). Operational use of the algorithm requires significantly more time than what was possible during the ART-X project. This is especially true for porting the algorithms to the hardware receiver. Nevertheless the knowledge and the code base grew by a number of key algorithms and will clearly facility more efficient and optimized IFEN receivers in the future, even for sophisticated applications.

4.5.2 ART-X Platform Trials

The ART-X RTK system consists essential of two components: a receiver core that is capable to acquire and track signals to generate code/carrier ranges, and a RTK kernel that runs independently on the operating system of the ART-X receiver.

The data exchange between receiver core and RTK kernel is done by RTCM while establishing TCP/IP connections. This covers the configuration of the RTK kernel, supplying of observations and ephemeris information, and fetching of PVT results.

4.5.2.1 RTCM Data exchange

For an flexible and extendable RTCM data exchange the receiver core was equipped with a dedicated RTCM interface that

- Supports the standard RTCM data exchange, at least for GPS L1/L2
- Has additions for the Galileo RTCM extension
- Supports the RTK kernel with proprietary messages

The implementation was performed in a modular way using C++ template methods to build arbitrary RTCM messages with low effort. RTCM data fields may be defined as types that may be used to construct RTCM message objects while safety of the message consistency is maintained by standard C++ approaches.

Message transmission may be performed via special TCP/IP layer while messages itself are treated as binary objects independent of the transport medium.

Efforts have been made that the TCP/IP connection may be performed either as server or client at the receiver core side. Additional, a periodic connection check is done to ensure a re-connection once the counter part terminated the TCP/IP connection. As it turned out, this was essential for testing to allow a fast restart of the receiver components without having to re-acquire all signals, as it would be necessary for a cold system start.

4.5.2.2 Data processing

RTK kernel was used in auto detection mode as above (though other modes would be configurable). This mode requires that RTK processing itself decides the number and type of observations. Because acquisition time of signals may vary, an algorithm was implemented to start RTCM generation first when a previously requested number of observation is available on all required frequencies (at least, GPS l1 and Galileo E1, E5a and E5b).

Once PVT solutions are available from the RTK kernel, these are scanned for validity and for a requested type (single point, differential, float solution, fix solution) and provided to the external user terminal. Additional for comparison the internal PVT may be provided to the user.

4.5.2.3 Epoch timing

To ensure that the measurement epoch of reference and rover receiver different algorithms were implemented. First, once a coarse time is available, the receiver uses this time to obtain the measurement epoch that, of course, may have an offset of 10-20msec. Additionally, an epoch steering may be enabled that uses the clock bias from the internal PVT computation, to correct the measurement epoch. It turns out that this may generate spurious effects on the carrier range; especially double difference tests become hard to investigate.

Third, it was chosen to run a measurement epoch correction once (and only once) when the clock bias is available from a proven internal PVT. This was the preferred choice for further testing giving a measurement epoch deviation of less than a usec.

4.5.3 RTK development tests

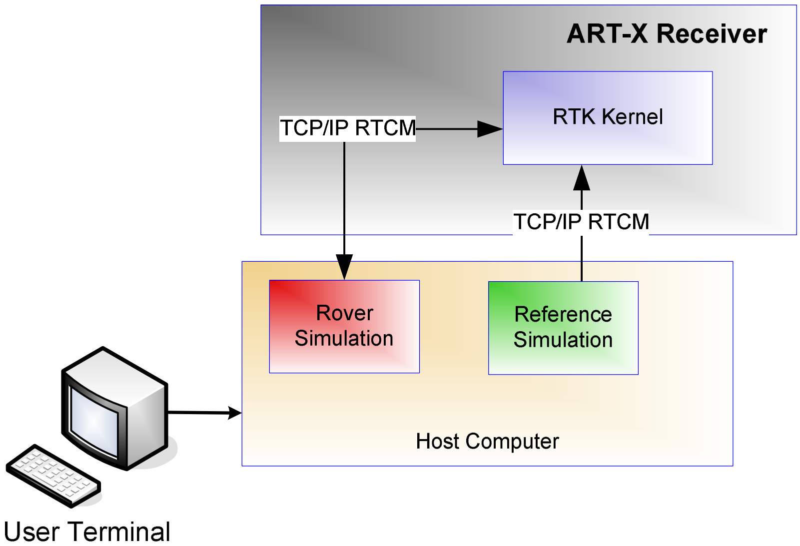
4.5.3.1 Unit Tests

To avoid problems of message data exchange a large set of stand-alone unit tests for the RTCM modules were developed. These cover data field consistency, message content, CRC computation and binary consistency checks.

4.5.3.2 Simulation Tests

To ensure that the complete message processing is correct, a host based simulation test was established. For this synthetic code/carrier ranges were generated from the IFEN CSim library that supports all aspects of a constellation and signal generation on GPS and Galileo. The simulation itself were applications (for reference and rover receiver) that run on a host computer in near real time, while connecting via TCP/IP to the RTK kernel that runs on the target platform.

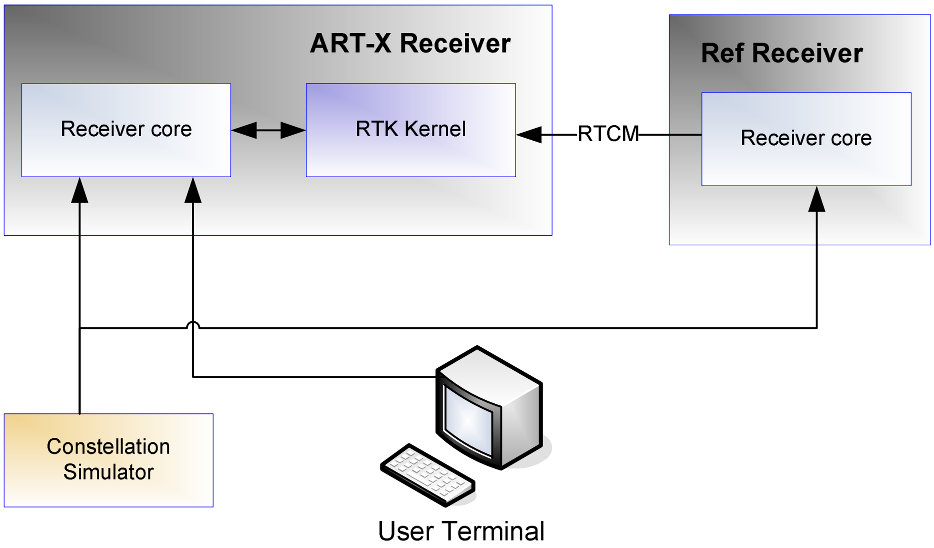
The net outcome of this simulation was that the connection with the RTK kernel could be checked, and that the data generation is consistent.



For an simulated offset of 2m in height the float/fixed solutions gave reasonable results. The spikes present and the float solution that seems to have a bias may indicate that the carrier/code ranges of the simulation were not generated consistently, most likely due to float precision problems.

4.5.3.3 Real signal RTK tests

For RTK tests with actual signals the ART-X receiver was set up to connect its receiver core with the RTK kernel when starting, and a second receiver was configured also to connect to the ART-X receiver on start up (or try to reconnect after RTK-kernel connection loss). For input first a zero-base line test was done by a single signal generator that was capable to generate GPS L1 and Galileo E1/E5a/E5b.



For this kind of setup the RTK kernel finally obtained valid fixed position solutions with zero offset between Reference station/Rover receiver. The processor load in nominal case for the RTK kernel was in the order of 25% for 6 GPS/6Galileo signals (i.e. 24 observations in total); the RTK kernel performed a reset each 5 sec so this could be considered as a reasonable nominal value. Occasionally, the RTK kernel started a deep search that lead to a higher RTK kernel processor load of roughly 75%.

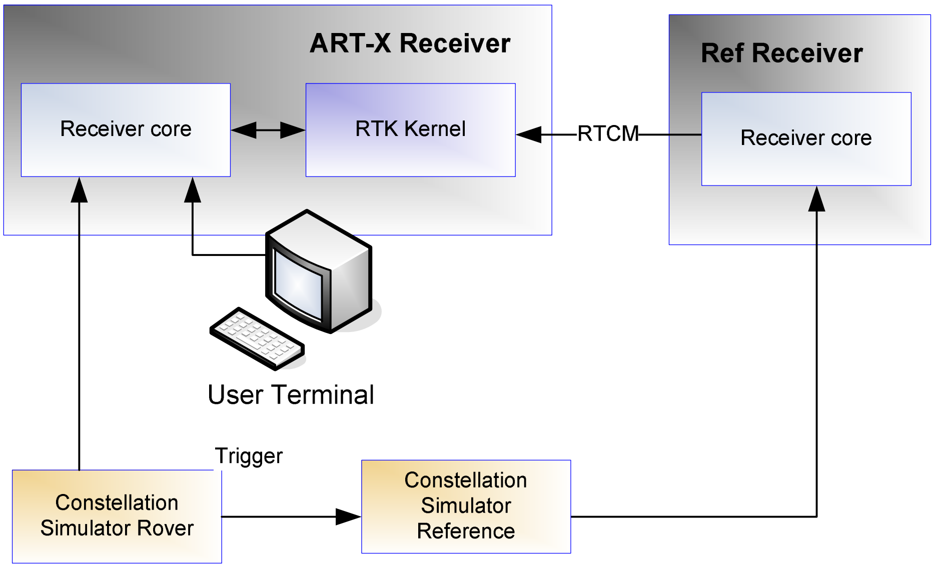
4.5.3.4 Double difference test

A basic test on RTK processing is to calculate for zero base line a difference between differences of two satellites on reference and rover receiver. The outcome must be a integer value (because all differences like clock and satellite motion cancels out). In general, this test was performed for all real signal tests to ensure its consistency.

4.5.3.5 Separate Ref/Rover tests

For real RTK tests two constellation generators were used, that trigger internally on session start. This also was the set up as reported in RTK test (18). Here also reference station and rover receiver start from a common position, and the rover moves after 10min. This gives sufficient time for the receiver to acquire and track signals, and to run a double difference check as above.

The reference station position was kept fixed, while the rover constellation either moves to a fix offset or runs a circular motion. A circular motion gives the advantage of checking a constant distance to the center of the circle.



4.6 Comparison and Conclusions of the ART-X Implementation

The main goal of the ART-X RTK system is to run a state of the art RTK algorithm on a receiver platform that is capable to process today GNSS signals as a closed box. One challenge was to give the RTK algorithm sufficient processing resources to obtain a fixed solution fast and reliably. The used OMAP 3 processor in most cases allowed this to achieve for a reasonable number of signals.

The test output of position solutions was not as good as expected according the RTK algorithms power. Despite it was not possible to pinpoint the cause it seems that it rather in the test setup than in the receiver itself (otherwise zero base line tests would not be as good as it had been). Provided that multiple frequencies of GPS/Galileo are available a fix solution was obtained fast (in the order of seconds once the tracking is established). The ART-X receiver demonstrated that is possible to run the RTK algorithm on a comparably small application processor, to obtain and use several different frequencies for measurements that are the base for future algorithms that well may be incorporated into a compact receiver platform.

5. Potential Impact

Please provide a description of the potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results. The length of this part cannot exceed 10 pages

One important topic to be considered here is to achieve the best possible exploitation of the ART-X developments trough proper commercialization, to ensure proper return-of.-investment. To maximize the exploitation efficiency, the ART-X receiver concept is fully in line with the IFEN internal roadmap for a next-generation GPS/Galileo/GLONASS professional receiver.

Eight fields of possible ART-X exploitation were identified and will be further detailed on the next pages. The following figure provides a high level overview of the possible exploitations and their relation with the ART-X project and the overall Galileo IOV/FOC schedule.

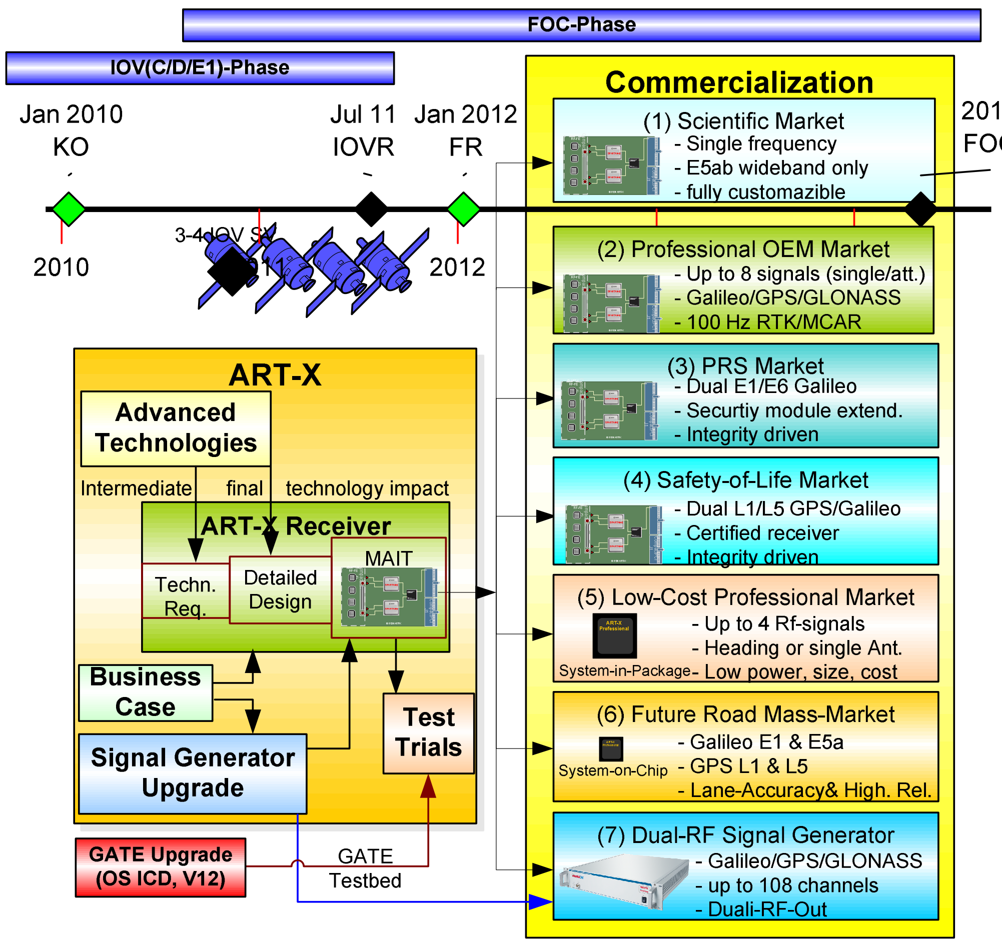


Figure 5-1: Overview of ART-X Exploitation of ART-X

Considering the current Galileo schedule, ART-X would run in parallel until the end of the IOV phase. The time until end of FOC can then be used for results exploitation through further commercialization by different custom developments.

5.1.1 IFEN

Concerning exploitation, IFEN is focusing on the following fields of exploitation:

(1) The exploitation towards the **'Scientific Market'** is an interesting niche market, as this market segment requires highly flexible receiver with customizable signal and navigation processing, combined with signal quality. Through the support of the Galileo E5ab wide-band signal, the currently best signal available in space can be made available for this user group. Here the return of investment is driven by special user customizations.

(2) The core market to be addressed with ART-X is the high-end '**Professional OEM Market'**. With the support of all GPS, all Galileo (including the 'Commercial Service' as far as defined) and also the GLONASS G1 frequency, the professional infrastructure and application market is the primary exploitation focus. Especially the reference receiver stations (CORS for IGS, GTRF, SAPOS…), but also the mobile user terminal market (e.g. in construction, agriculture, high precision positioning …), taking full advantage of the ART-X integrated user terminal capabilities can be fully addressed by ART-X. Furthermore the unique capabilities of the ART-X OEM board with its integrated 'terminal interfaces' (external memory, data interfaces, LCD driver, support for 2D/3D graphics) will enable many vertical integrators to provide solutions for the end user market with low cost of integration, less external components and only limited delta developments. This will be attractive especially for new players or small players in the vertical professional application market.

(3) Based on ART-X, the exploitation towards **PRS receiver capability** is manly driven by the integration of a security module, the related key handling capabilities and appropriate extension of the ART-X board for tamper-resistance. Galileo E1 and E6 signal capability is just a matter of configuration of the ART-X board with the proper discrete RF-Front-End components, with optimized signal rejection filters (against out-of-band interference) and the extension of the navigation processing with integrity capability.

(4) Targeting the **'Safety-of-Life'** market, with a discrete RF-Front-End with optimized out-of-band signal rejection (interference), integrity processing algorithm enhancements and certification readiness for aviation or other SoL applications is also a possible direct exploitation opportunity for the ART-X board. With its support for GPS L1/L5 and Galileo L1/E5b all necessary signals will be supported. Also targeting 'Liability Critical Service' would be possible, as soon as more details will be defined for this type of market.

(5) In the future, if realizing the ART-X FPGA based signal correlator engine in an ASIC HW-correlator-engine, also advanced possibilities of packaging as 'System-in-Package' are possible. By stacking an application processor die and a signal correlator ASIC die on top of each other, these chips would form a complete base-band receiver in a single chip-package. The 'SiP' packing is suited for market with medium number of receivers, where a 'SoC' approach is too expensive. Thus the 'SiP' approach could be turn out to be the perfect trade-off between the professional market size (in terms of receiver units per year) and an attractive 'chip package' price, size and power.

(6) The lowest possible price, size and power can be achieved when combining the RF-ASIC IP, the ASIC correlator IP and the applications processor IP (e.g. ARM 8Cortex) in a single 'system-on-Chip' solution. This would require a large investment in integration of different IP's in one chip, but also the chip manufacturing preparation. Therefore this approach is only suited if the unit number of chips reaches a number above (estimated) 1 million units per year. This unit number is only the case for the mass-market, but not the classical 'professional market'. However the automotive market could evolve in the next years into this direction, requesting dual-frequency and dual-constellation capability, to enable new innovative applications for the road (position-on-lane awareness, lane-accurate guidance, lane-change-warning, guidance to an individual parking place…). The automotive (but of course also the road tolling market with its liability and reliability requirements) market is currently the only mass market, which could evolve into the dual-frequency capability domain due to the advanced applications being discussed currently at the big automotive manufacturers. Due to this, this could be an extremely promising exploitation area during the next 5 years.

(8) The availability of a signal generator with multiple RF-outputs would be a major step beyond the current capabilities of the IFEN/WORK 'NavX-NCS' signal generators, which are currently supporting all frequencies and system in a flexible manner, but limited to one RF-output. This would allow offering the potential customer a broader product portfolio, allowing 'shopping' out of one hand. As heading application, especially to the high growth in the agriculture market, will gain more market shares, also the availability of a heading/attitude capable RF-signal generator solution will be key driver for long term commercial market success. Therefore also this is an important topic for exploitation

5.1.2 WORK

As WORK is responsible for the hardware part of the NavX-NCS signal generator, the same motivation as for IFEN applies here. With the availability of a multiple RF-output capable signal generator, new segments of the GNSS equipment test market can be targeted. This is especially important to provide the customers with a complete product portfolio covering different applications. It is expected that the new market segments will recover the investment within two years.

5.1.3 inPosition

inPosition develops real-time RTK software for various applications. One strategic target is the bundling of the software with state-of-the-art GNSS technology. The development of the ART-X receiver provides an ideal strategic platform to host our RTK software. This allows the marketing of inPosition's software with completely separate hardware and requires no need of differentiation to internal RTK components as available with presently available OEM boards.

The developments with the ART-X project are an extension respectively a continuation of the successful cooperation during the joint ARTUS project.

5.1.4 PRCH

At Primechange we see the participation on the ART-X of strategic importance. There are four main benefits for us to participate in this project:

- Exposure to our first FP7 project will give us the opportunity of developing new partnerships and contacts with key players in the European GNSS ecosystem. We expect that some of these relationships will lead to further collaboration beyond the work frame of ART-X.
- Consolidation of market knowledge and expertise in the GNSS and LBS market. We have participated and have previous experience in doing research for higher level GNSS technology (marketing and research on PND software, mass-market mobile solutions, etc). We also posses excellent technological know-how in GNSS receivers and simulators. Hence, ART-X offers the possibility to expand our market knowledge into fields where we have good technology background.
- Our goal is to become a European reference in overall GNSS and LBS consulting and ART-X is an important piece in the puzzle to reach that goal. The results of our work in ART-X will enhance the know-how we have to offer to our potential clients.
- Portfolio diversification. Most of our work is in the private sector. We would like to translate our performance-based methods into public funded projects. The objective is to consolidate our public sector portfolio to reduce the risks during periods where private investment is scarce (such as what we are experiencing in current times).

5.1.5 UniBwM

The algorithms developed and implemented within the ART-X project are of high interest for the Institute of Geodesy and Navigation. Interference monitoring algorithms are useful for all high accuracy users especially for reference stations and safety critical applications. The developed algorithm(s) will be adaptable for the institute's GNSS software receiver and will be implemented. The implementation will provide a powerful monitoring instrument usable within future developments, e.g. for assessments of reference/monitoring station locations. The ionosphere correction algorithms based on a 3rd frequency will enhance precise PVT solutions and will contribute for high accuracy positioning solutions developed at the institute. Different RTK algorithms have been successfully used within several research studies at the UniBwM. The realtime RTK/MCAR algorithm will provide a significant enhancement for the RTK engine already existing at the institute of geodesy and navigation and will be implemented into the RTK engine. The usability of commercial services providing RTK data will be upgraded in general because fast and reliable RTK positioning can be provided with RTK/MCAR algorithms. Beside powerful monitoring applications and enhanced PVT solutions the ART-X project will provide a gain of knowledge for the institute which can be used or future developments and within education.

6. Project Contact

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