PROJECT PERIODIC REPORT

Publishable Summary

Grant Agreement number: 214911

Project acronym: ICESTARS

Project title: Integrated Circuit/EM Simulation and design Technologies for Advanced Radio Systems-on-chip

Funding Scheme: Small or medium-scale focused research project (STREP)

Date of latest version of Annex I against which the assessment will be made: 18-01-2010 (DoW Version 3.0 accepted with Amendment AM2)

Periodic report: 1st ☐ 2nd ■ 3rd ☐ 4th ☐

Period covered: from February 1, 2009 to January 31, 2010

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the grant agreement
[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

1. Publishable summary

1.1 General overview

The research project “ICESTARS – Integrated Circuit/EM Simulation and design Technologies for Advanced Radio Systems-on-chip” under grant agreement no. 214911 started on February 1st, 2008 for a period of 2.5 years. The initial beneficiaries of the project are NXP Semiconductors B.V., Qimonda AG, AWR-APLAC Corporation OY, MAGWEL N.V., Fachhochschule Oberösterreich, Universität zu Köln, Oulun Yliopisto, and Bergische Universität Wuppertal. In 2009 Qimonda AG stopped project participation. New partners are: Infineon Technologies AG and Teknillinen korkeakoulu (TKK - Helsinki University of Technology; recently merged into a foundation-based Aalto University).

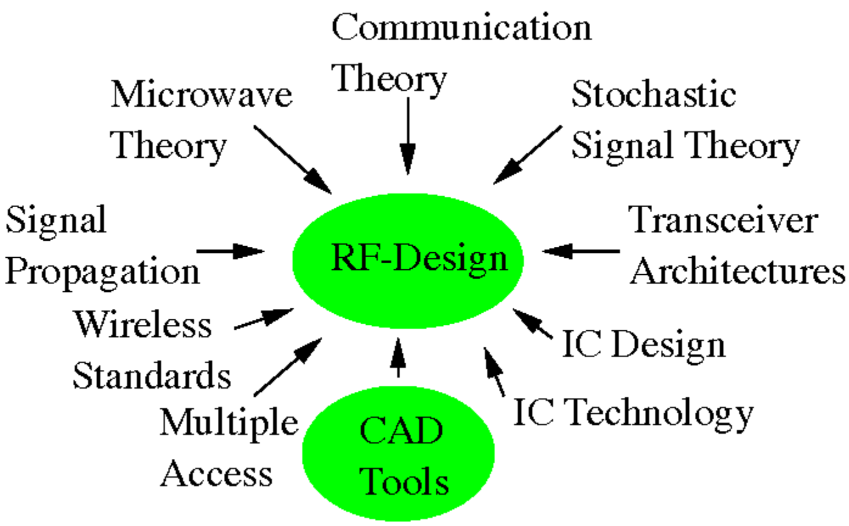

Fig. 1..1 – The RF design as an interdisciplinary challenge.

As depicted in Fig. 1.1, RF design is a truly interdisciplinary task ranging from the theoretical background of communication and microwave theory to IC technology and IC design. The research project is focussed on the challenges of CAD design tools. The future demand of low cost mobile communication requires broader bandwidth and therefore the opening of new areas of the communication spectrum for mass products, because large pieces of the spectrum at lower frequencies have already been allocated by legacy communication systems. Therefore, the channel beyond 10 GHz is of a huge economical interest.

The RF designs therefore must keep pace with the higher demands of signal bandwidths, centre frequencies and various wireless communication standards to be fulfilled by the same transceiver architecture. One central challenge is to supply RF designers with CAD tools for simulating and predicting signals at different stages of the transceiver front-end.

The project is split into six work packages (WPs). Four of these WPs are focused on technical and scientific work in the project according to a well-defined and coherent set of activities: WP1 - Time-Domain Techniques; WP2 - Frequency-Domain Techniques; WP3 - EM-Analysis and Coupled EM-Circuit Analysis; WP5 - Validation. The two additional WPs are focused primarily on the project communication and management tasks: WP4 - Knowledge Management and WP6 - Project Management.

2. Short summary of the achievements

2.1 Project Achievements

In the Year 2 (Feb 2009 - Jan 2010) the ICESTARS project managed the consequences caused by the leave of QAG (due to insolvency) on April 1, 2009. Two new partners, IFX and TKK/Aalto, took over former tasks of QAG and measures to deal with the caused delay were taken. Despite this turmoil, all but one deliverable were submitted in time. One Year 1 deliverable was re-submitted due to the new situation. One Milestone had to be shifted in time. All Deliverables prove the technical and scientific progress made in Year 2.

Between April-Sept. 2009 the contact with the former QAG-team was maintained on an informal base (using private phones and email addresses). As partner IFX they joined ICESTARS in month 20 (Sept. 1, 2009); TKK/Aalto joined in month 22 (Nov. 1, 2009).

During the project more interaction between partners was set up: WUP-IFX, WUP-NXP, APL-TKK/Aalto, APL-OUL, MAG-KLN-NXP, KLN-WUP. A public Project Workshop was held at Hagenberg, Austria, organised by FHO and KLN. Here also further dissemination to the partners was achieved. The publications submitted for the post-conference book of the important SCEE-2008 conference (Espoo, Finland) were all accepted after a careful review process. This included two invited papers. Further publications were made in technical journals (mathematical ones as well as in IEEE). KLN submitted a general publication ”Mathematics for next generation radio chips” in Public Service Review: Science & Technology 6 (2010).

2.2 WP1 – Time Domain methods

The high data rates with their corresponding huge requirement of signal bandwidths on the one hand and the high centre frequencies of several GHz on the other led existing CAD tools to their limits. Employing standard solvers for ordinary differential algebraic equations (DAEs) leads to huge run-times, because the time-steps of the solvers must be smaller than the inverse Nyquist rate of several GHz. To overcome this problem with the Nyquist rate in the nineties a novel method has been developed, circumventing the Nyquist rate problem. Essentially, a carrier signal and its envelope modulation are split – a technique already well known in linear system theory as the Equivalent Complex Baseband (ECB). However, this ECB technique cannot be applied to nonlinear differential equations. The novel method is based on reformulating the ordinary DAE by a system of partial differential equations (PDEs). The formulation of the PDE depends on the specific problem under investigation. This basic method plays therefore also an important role in WP2.

Finite-Difference (FD) or Ritz-Galerkin methods can realize the numerical solution of the PDE. The three tasks of WP1 deal with the solution of the various kinds of PDEs by wavelet methods. WP2 on the contrary deals with solving the PDEs by a trigonometric basis, known as the Harmonic Balance method (HB). Is has been shown that a wavelet basis is superior to HB when sharp signal transients occur due to its property of a local refinement.

Task T1.1 is called “Wavelet-based algorithms for mixed analogue/digital simulations”. Standard methods approximate the signals by a truncated Taylor series or a rational polynomial. This approximation is however not well suited for the signals occurring in mixed signal simulations. Task T1.1 addresses an alternative by employing a wavelet basis. Specifically, a spline wavelet basis has been investigated and implemented employing an adaptive grid refinement. The method has been implemented into the TITAN simulator of IFX and tested successfully for the circuit examples of WP5. Currently, modifications are tested to speed up the convergence rate.

Within Task T1.2 “Multirate methods based on wavelet approaches” broadband signals such as CDMA or OFDM signals are represented in a much more efficient way than traditional techniques. The multirate problem is reformulated by a partial differential equation (PDE). A wavelet basis allows for the construction of adaptive grids in the multivariate domain of dependence. The wavelet-based method has been implemented into the TITAN simulator. The test phase is delayed due to unpredictable reasons.

Task T1.3 “Multirate Envelope Methods” addresses the general problem of simulating circuits driven by multirate signals originating from demands of state-of-the art modulation techniques as discussed above. This task uses the same (PDE) formulation as Task T1.2. Unlike this task, novel finite difference schemes (FD) are employed which are favourable for oscillators. Moreover, optimal sweep following techniques have been developed and coded. The codes are at the moment in the test phase and validated for the designs in WP5.

Especially suited are cubic and exponential splines due to their simplicity of implementation. One drawback of a spline wavelet basis has been solved: the postprocessing of the results for getting designer relevant information such as the 1 dB compression point or the IP3. By postprocessing of the numerical solution the results can be cast into the standard notions based on Fourier spectra. FD schemes have been adopted to cope with oscillatory autonomous systems.

Technical Deliverables D1.1 "Report on the wavelet-based simulation technique" (T0+20), D1.2 "Report on the multirate wavelet and envelope techniques" (T0+20) have been delivered in time. A first version of D1.3 "Description of the envelope steady state and mixed time frequency method" (T0+30) has been made. Software modules for wavelet simulations and for envelope time integration have been developed. Modules are simulator independent. WUP assists in testing code with IFX and NXP.

A special WP1 meeting on Feb. 10, 2010 in Munich focused on solving common convergence problems for industrial problems. At the Project Workshop in Hagenberg dissemination was made to the partners on background of wavelets and on simulator independent software development. A researcher from WUP will give lectures on wavelet techniques at NXP. A Researcher from WUP weekly visits IFX for testing and optimal implementation.

2.3 WP2 – Frequency Domain Techniques

This WP deals with the well-known Harmonic Balance method for multitone signals, i.e. the representation of the signals by a Fourier expansion. The number of fundamental tones lies between 2 and 4. More than two fundamental frequencies cause a huge amount of Fourier coefficients resulting into a huge number of algebraic equations. This WP addresses the run-time problem in two ways. Firstly, the emergence of multiprocessor CPUs can be exploited when employing iterative preconditioned solvers with which multi-threading of the HB code is possible.

Secondly, the size of equations can be further reduced by an adaptive choice of the number of Fourier harmonics. This requires a diagnostic tool for estimating the truncation error and to adapt the number of unknown coefficients during the iterative process. Such a diagnostic tool will be implemented. A severe problem in HB analysis is to find a good initial guess for reducing the number of Newton iterations. Otherwise, non-convergence or a huge amount of Newton steps with an exploding run-time may result. To overcome this problem damped Newton solvers have been realized. Another problem is the tendency of HB to converge towards trivial (DC) solutions in the case of autonomous systems (oscillators). New algorithms for avoiding these trivial solutions are under development. The Volterra-on-HB (VoHB) method, originally developed at the University of

Oulu in recent years, exploits an efficient frequency domain convolution, and by a prototype of fast Volterra-based harmonic load-pull setup.

Task T2.1 “Scalable algorithms for RF simulations” concerned the implementation of an HB analysis interface that allows Tensor-Krylov based analysis (instead of classic Inexact-Newton based). It allows changing the HB solver to another one. More knowledge is gained from nodal vs. piece-wise HB multithreading capabilities. Most of the implementation details and the algorithm improvements have been studied and/or are tested for the hierarchical GMRES development.

Task T2.2 “Adaptivity in Harmonic Balance” covered the first versions of the HB diagnostic tool being implemented in APLAC (of APL) and TITAN (of IFX). An algorithm utilizes the results of the diagnostic tool and changes the HB-preconditioner based on change in the iteration count when compared to the earlier sweep points. A new initial guess approach for N-tone HB analysis has been developed using an initial 1-tone solution followed by a complete N-tone analysis. Recognition of weakly DC connected nodes in HB has been implemented.

Task T2.3 “Initial Conditions for Harmonic Balance” covered two aspects. Optimization based HB oscillator analysis can use transient analysis to obtain a better initial guess. This results in huge robustness increase in oscillator analysis, since the difficult circuits, e.g., ring oscillators, are typically easy for transient analysis, but very difficult for HB using DC as the initial guess. A further improvement is found in an improved Newton formulation. Here a link to generalized eigenvalue methods is exploited.

In Tasks T2.4 “Improvements of the Volterra-on-HB method” and T2.5 “Developing analysis and dimensioning tool for RF power amplifier”, the most important results during the 2nd year are that now, multi-device circuits using any simulation device models can be analyzed, as the AIF interface allows direct access to some of APLACs internal data structures. A good reference to achievements is: J.P.Aikio, M. Mäkitalo, T. Rahkonen, "Harmonic Load-pull Technique based on Volterra Analysis", Proceedings of the 39th European Microwave Conference, pp. 1696-1699, Rome, Italy, Sept. 2009.

Technical Deliverable D2.3 “Report on the dimensioning tool for optimising the harmonic matching of an RF power amplifier” (T0+24) has been delivered in time. A first version of D2.7 “Report on Improved initial conditions for HB” (T0+30) has been made.

Oulu provided dissemination to the partners at the Project Workshop in Hagenberg, Austria.

APL and OUL have an intensive cooperation. TKK/Aalto joined the project for work in WP2 and has cooperations with APL and with NXP.

2.4 WP3 – EM Analysis and Coupled EM-Circuit Analysis

The second period aimed at the realization of the software modules for transient field solving. In particular, the modules were developed for allowing EM field solving within circuit simulation where the “AV” field solver that evaluates the Poisson potential and the vector potential, has been selected for the EM part. For the circuit simulation the MECS solver that was developed at Köln was selected. Besides focussing on this coupling whose realization was done using API (application programming interface), a stand-alone sector in the field solver was provided for transient simulation tasks. Deliverables D3.2 and D3.3 have been provided in due time. Whereas in the first reporting period the coupling of the EM solver and the MECS solver was based on file exchange and only applicable for *linear* EM systems (it suffices to grab the state-space matrices only once), in the second reporting period, the coupling through the API is done by exchange of pointer data, and the MECS solver can act as a master process that directly gets control over the field solver. The field solver's API allows for overwriting the field 'state' and extraction of the time-derivative Jacobian and right-hand side both for linear *and* non-linear field systems. Finally, we would like to emphasize a few more achievements that were realized in this reporting period. The MECS solver has successfully simulated a VCO (from the benchmark set) with 6 transistors, 5 resistors, 6 capacitors and 4 inductors. The benchmark VCO is a voltage-controlled oscillator, the core of a PLL circuit for an RF transceiver. Fig. 1.2 and Fig. 1.3 show the transient response of the oscillator simulated by the simulator package MECS.

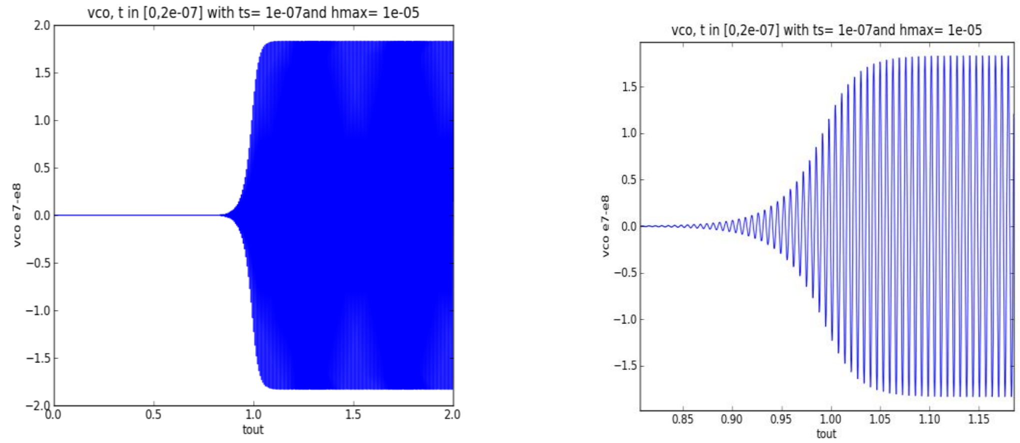

Fig. 1.2 Voltage-controlled oscillator with t in [0;10^{-7}] (left) and t in [$0.8*10^{-7}$,$1.2*10^{-7}$] (right). It generates a 1.8 GHz signal with amplitude 1.8V.

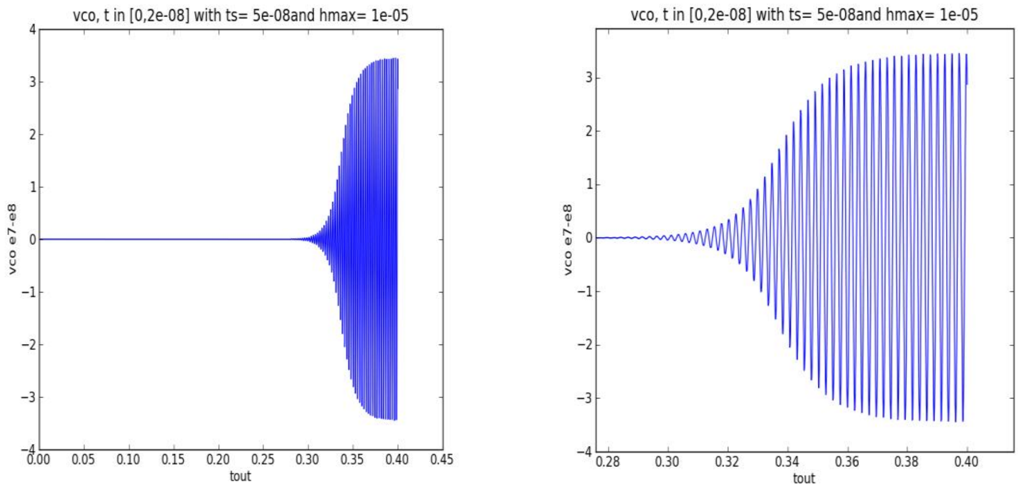

Fig. 1.3 Voltage-controlled oscillator with t in [0;$0.4*10^{-8}$] (left) and t in [$0.28*10^{-8}$,$0.4*10^{-8}$] (right). It generates a 36 GHz signal with amplitude 3.6V. In comparison with the VCO in Fig. 1.2, the geometries of the transistors have been reduced by a factor of 1/10. Furthermore, the parameter values for the resistances, capacitances and inductances have been adapted.

The AV field solver was equipped with a GUI based on a DOM (document object model) that allows for error-free input file generation. An illustration of a typical GUI appearance is shown in Fig. 1.4.

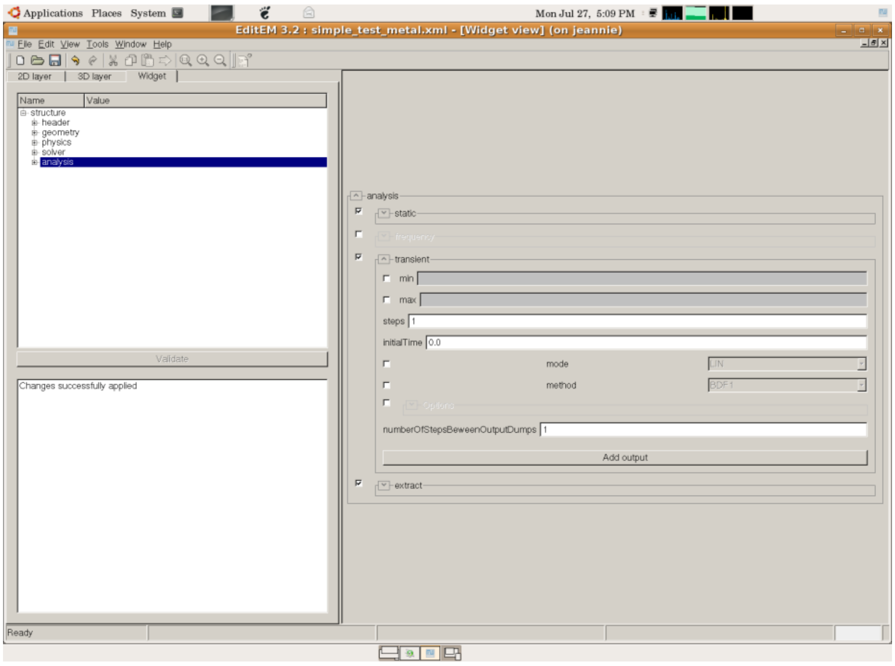

Fig. 1.4 Menu screen to upload transient input settings.

Further insight studies were performed to enhance the robustness of the AV solver. Of particular, interest is the behaviour of the condition number of the system matrix as a function at high frequency. Performing a change of variables for frequencies above 100 GHz did provide first successful simulations. Although not directly being part of ICESTARS, the transformation was implemented with modules for the transient sector as well.

Another idea that was suggested by NXP is the isolation of the smallest eigenvalue, as it appears it depends on the inverse of the frequency. This would also explain the high number of iterations in iterative solutions.

NXP have also investigated alternative algorithms for coupling EM and circuit simulations, by further developing algorithms for the simulation of the influence of power amplifiers on voltage controlled oscillators and balanced-unbalanced (so-called 'balun') circuits. The algorithms have been shown to yield accurate results that can be used in a design environment. This work is strongly related to WP2.

Technical Deliverables D3.2 "Report on the implementation of the RF boundary conditions and the transient simulation with adaptive computing facilities"(T0+20) and D3.3 "Software modules for RF boundary conditions and transient simulations" (T0+20) have been delivered in time. Several first versions of sections in Deliverable D3.4 "Report on EM field solving within circuit simulation, optimisation of device designs based on RF condition and reference benchmarks for mixed-signal designs" (T0+30) have been put on the Wiki.

KLN provided dissemination to the partners at the Project Workshop in Hagenberg, Austria. KLN and MGW closely work together and have regular meetings. Test examples are discussed with NXP. PhD-students of WUP and KLN are meeting regularly, discussing the topic of coupling Maxwell's equations and circuits, index concepts, etc.

2.5 WP4 – Knowledge Management

The ICESTARS public website (http://www.icestars.eu; see also Fig. 1.5) has been re-structured and updated including detailed descriptions of the project achievements in the various research areas. As the ICESTARS research comprises various areas of radio frequency design that are highly complex, a glossary has been added. The glossary lists the acronyms of difficult or specialized terms with their accompanying definitions employing an alphabetized, dictionary-style format.

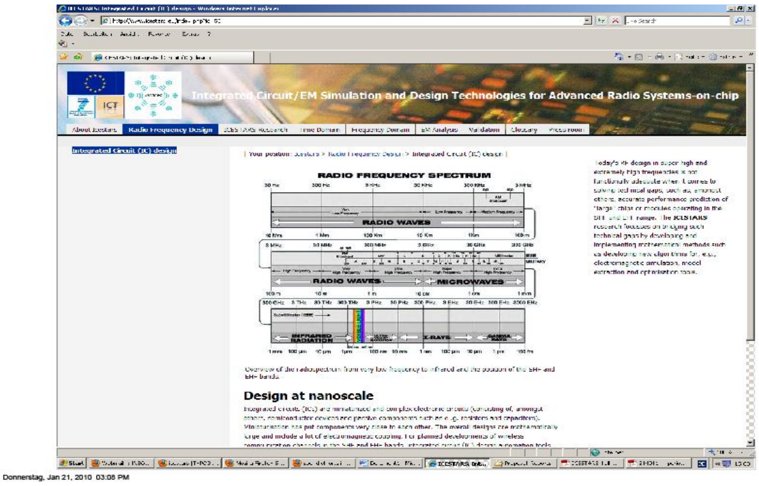

Fig. 1.5 Screen shot of public website.

All ICESTARS partners were present at the joint Project Meeting and Project Workshop in Hagenberg, Austria. Apart from the exchange of know-how between the partners, the meeting also had a public part where the ICESTARS achievements were presented. As an invited speaker U. Knöchel of Fraunhofer EAS, Dresden, presented the Fraunhofer Institute for Integrated Circuits working areas in modelling and simulation of analogue and digital circuits, followed by presentations from the ICESTARS research areas. All presentations are available on the ICESTARS internal Wiki. In the internal part of the meeting further presentations were given on algorithmic details by WUP, OUL and KLN. Also simulator independent software development was discussed. These served the dissemination between the partners.

The focus of ICESTARS information dissemination activities has been on results. Some achievements were made available to a broader public via conference papers; in addition some partners have published articles in Scientific Journals featuring their achievements; also two Master-of-Science-Theses were published presenting detailed research results.

WP4 focuses on *dissemination* as well as *exploitation and use of the results* achieved by ICESTARS. While dissemination focuses on strategies to distribute information about the project's progress and results, exploitation and use present the exploitation of the project results to add commercial and scientific value to their respective companies and institutions. ICESTARS aims at not just supporting the immediate propagation and use of project results but also at promoting a close cooperation of the ICESTARS partners and exchange of knowledge beyond the lifetime of this project.

Deliverable D4.2 "Dissemination and use plan" (T0+22) has been submitted. This includes contributions from the new partners IFX and TKK (see 1.2.7).

KLN submitted a general publication on ICESTARS achievements "Mathematics for next generation radio chips" in "Public Service Review: Science & Technology 6 (2010)".

2.6 WP5 – Validation

The sudden leave of QAG from the project on April 1, 2009, caused questions by the reviewers at the Review Year 1 on how to deal with the test examples collected in the Deliverables D5.1 “Tool development test set and data format specification” (T0+6) and D5.2 “Specification of validation tests (test plan)” (T0+15). In June 2010 answers were provided (legal issues) and alternative tests have been defined. The reports have been resubmitted (July 2010).

At the Project Workshop in Hagenberg steps for the Validation Phase (starting in Dec. 2009) have been defined. As first step a first version of Deliverable D5.3 “Final validation report” has been made (Dec. 2009; T0+30).

2.7 WP6 – Project Management

The internal Wiki is actively used for archiving project documents (like Versions of DoW), response for reviews, project deliverables and presentations. Regular communication and progress monitoring was handled through monthly teleconferences by the Project Management Team (PMT).

The outcomes of the review on Year 1 have been implemented by the PMT. First two contingency plans were defined how to deal with QAG being in insolvency. Next two Amendments (AM1 and AM2) were prepared in cooperation with the Project Officer and NXP's partner in legal and finance for subsidy projects, PNO Consultants.

AM1 (using DoW Version 2.0) dealt with QAG leaving the project and WUP temporarily taking over tasks and staff from the former QAG team (to guarantee essential knowledge remaining available to the whole project team and to give the QAG team the best chance in their process to transfer as a complete team to Infineon Technologies AG; shortly after this they were able to rejoin the project as IFX - see AM2).

AM2 (using DoW Version 3.0) dealt with introducing Teknillinen korkeakoulu (TKK - Helsinki University of Technology, Espoo, Finland) and Infineon Technologies (IFX, Munich, Germany) as new partners for the remainder of the project, to take over execution of former QAG/WUP tasks as well as to cover delay. TKK only operates in WP2. IFX joined Sept. 1, 2009; TKK joined Nov. 1, 2009.

Recently (Dec. 2009), QAG confirmed that they will not claim costs for Year 2.

On June 1, 2009, Marq Kole ended his role as the Project Coordinator at NXP. Since that date Jan ter Maten takes over this role.

On Jan 1, 2010, Helsinki School of Economics, the University of Art and Design Helsinki and Teknillinen korkeakoulu (TKK - Helsinki University of Technology) merged into a foundation-based Aalto University. The name TKK is used in the current reporting.