Evaluation of the QIPC Cluster Review

Review dates: 14 – 16 February 2005 in Innsbruck
Review period: 01/01/2004 – 31/12/2004
Subject to the review: thirteen projects in the area of QIPC funded by FET in FP5
QIPC Proactive Initiative and FET Open
Future and Emerging Technologies, DG INFSO, European Commission
FET QIPC PI coordinator: Antonella Karlson

Dr. Tommaso Calarco (CNR-INFM R&D Centre on Bose-Einstein Condensation, Trento, Italy) wrote a cluster review report which was sent to all parties involved. Please find below excerpts from this report.

Acronym	***Title***	***Project aim***
ACQP	Atom-Chip Quantum Processor	Controlling **neutral atoms** by electromagnetic fields on **micro-fabricated surfaces** for scalable quantum computing, investigating and reducing decoherence mechanisms
ATESIT	Active Teleportation and Entangled State Information Technology	Exploring the power of **entanglement with photons** and implementing novel entanglement generation schemes
EDIQIP	Effects of Decoherence and Imperfections for QIP	Understanding and suppressing the effects of **imperfect operating conditions** and other **decoherence sources** on the fidelity of quantum computations
ESQUIRE	Experimental realization of quantum gates and development of scalable quantum computer schemes in rare-earth-ion-doped inorganic crystals	Theoretical and experimental implementation of a few-qubit quantum processor using **rare-earth ions** in an ionic host matrix material.
PROSECCO	Protocols for Secure Computations	Studying **small scale distributed quantum computations** for accomplishing tasks which could not be securely implemented classically
QGATES	Quantum Gates and Elementary Scalable Processors Using Deterministically Addressed Atoms	Realizing multiple qubit quantum gates with individually-addressable **trapped ions**, **trapped atoms** and (optical/microwave) **cavity QED** systems.
QIPD-DF-ROSES	Quantum Information Processing Device using Doped Fullerenes and with the Read-Out of Single Electron Spin	Demonstrating few-qubit quantum information processing using an efficient single electron spin readout technology in Group V **endohedral fullerenes**
QUPRODIS	Quantum Properties of Distributed Systems	Investigating **theoretical foundations** of quantum **distributed** information processing, and the role of **entanglement** in this field
RESQ	Resources for quantum information	Devising new **protocols and algorithms** for processing information at the quantum level, particularly in **networks** and **distributed systems**, and in the presence of noise
	pRobabilistic gAtes Making	Developing technologies supporting elementary scalable quantum processors and robust optical

RAMBOQ	Binary Optical Quanta	links between separated quantum processors using **conditional linear optical logic**.
SAWPHOTON	Single electron source generating individual photons for secure optical communications	Building a novel **single-photon source** based on **electrical injection** for quantum information processing, and, in particular, for quantum cryptography.
SQUBIT 2	Superconducting Qubits: Quantum computing with Josephson Junctions	Achieving reliable operation of single **superconducting qubits**, and fabricating, testing and operating **2-qubit circuits** with **charge-phase** and **flux qubits**
TOPQIP	Topological Quantum Information Processing	Proposing schemes for the control and detection of **geometrical** and **topological phases** in quantum systems, ranging from ion traps to solid state systems and cold gases
Total number of projects addressing each of the FET-QIPC objectives		

Table: Summary description of the objectives of each of the projects reviewed in the Cluster Evaluation

EU QIPC Roadmap subject category	*Projects addressing the subject*
Quantum Communication	
Fiber-based systems	RAMBOQ, SAWPHOTON
Free-space systems	ATESIT,RAMBOQ
Quantum interfaces and memory	QGATES
New applications and protocols	ATESIT, PROSECCO , QUPRODIS, RESQ
Quantum Computing	
Trapped Ions	QGATES
Atoms and Cavity QED	ACQP, QGATES
Superconducting Circuits	SQUBIT-2
Semiconductor quantum dots	none
Linear Optics Quantum Computation	RAMBOQ
Impurity spins in solids	ESQUIRE, QIPD-DF-ROSES
Quantum Information Science –Theory	
Quantum algorithms and complexity	RESQ
Computational models and architectures	RESQ, TOPQIP
Quantum simulations	QUPRODIS
Quantum error correction and purification	EDIQIP, PROSECCO
Theory of entanglement	ATESIT, QUPRODIS
Multi-party entanglement and applications	PROSECCO, QUPRODIS, RESQ
Noisy communication channels	RESQ
Fundamental quantum mechanics and decoherence	TOPQIP

Table: Relevance of the FET projects to the QIPC subfields as described in the European QIPC Roadmap

Project	*Main recent achievements*
ACQP	• Created conductors of a quality sufficient to **avoid** the problems of spatial **fluctuations** of the **magnetic field** via **ultra smooth films** • Spatially resolved **measurement** of **magnetic potential corrugations** at **10^{-5} level** using Bose-Einstein condensates as a probe • Achieved long **quantum coherence**, similar to **atomic clocks**, between qubit states trapped on an **atom chip**
ATESIT	• Produced **hyper-entangled photon states** (entangled both in polarization and in orbital angular momentum) exploiting micro-machined spiral phase-plates. • Realized **experimental optimal cloning** of one-to-two and one-to-three qubits using a quantum injected optical parametric amplifier developed previously • Developed a **general classification of Bell states**
EDIQIP	• Determined a **universal law**, based on random matrix theory, for the computation **fidelity decay** induced by **internal static imperfections** • Established the **universal accuracy bounds** for quantum computation in presence of **residual static couplings** between qubits • Developed a generic **Pauli random error correction method** (PAREC) which allows to suppress by orders of magnitude the effects of static errors
ESQUIRE	• Demonstrated the **preparation** of suitable sub-ensemble **of ion pairs** with the **desired inter-ionic coupling** to do gate operations • Achieved coherent qubit **state-to-state** transfer **efficiency bigger than 95%** • Devised **highly optimized pulse shapes** to improve qubit selection and gate operations in speed and efficiency

PROSECCO	• In the information theoretical part of the work: further analyzed **security aspects** within various **protocols** including loopholes in the Vienna bank transfer • In the physics part of the work: reported the **scaling** behavior of multi-partite states (**graph states**) • Proved a **composition theorem** for **modular design of protocols**
QGATES	• Showed quantum **teleportation** of **ion states**, the realization of **three-ion entangled states**, and the observation of a **20 second entanglement lifetime** • Achieved controlled **manipulation** of single atoms in a **five-atom string** in a dipole trap • Realized loading of **Bose-Einstein condensates** in **micro-traps** and in **optical lattices**
QIPD-DF-ROSES	• Produced N@C_{60} and P@C_{60} **endohedrals** with high degree of purification • Demonstrated **controlled single NV** (Nitrogen-Vacancy) **defect implantation** with nm resolution and **NV-endohedral coupling**. • Recorded EPR spectra, improving the previously **measured T2 time** from 1 µs to **350 µs** at **room temperature**).
QUPRODIS	• Novel method to create **long distance entanglement** in an array of **nano-electromechanical systems** • Hamiltonian models on optical lattices for conceptual **interfacing** of **entanglement theory** with **quantum phase transitions** in standard lattice models • Studied **graph states** with respect to **purification** in presence of noise, effect of **decoherence**, definition of the Kolmogorov **complexity**
RESQ	• Devised a provably **secure** protocol for **string flipping** which circumvents the no-go theorems about quantum bit commitment • Developed the concept of **projected entangled pairs** as a powerful generic tool to study many-particle quantum systems • Proved that **adiabatic quantum computation** is fully **equivalent** to **standard** quantum computation
RAMBOQ	• Developed a high-efficiency **source** of pure-state **single photons** based on quantum dots in pillar microcavities • Built a cascadable **two-qubit CNOT** gate with **80% measured fidelity** • Performed **real-world** QIPC demonstrations, like teleportation across the Danube and a **bank transfer via quantum cryptography** in an intra-city link.
SAWPHOTON	• Demonstrated several **technological solutions** during the process of producing an acoustic actuator of electronic waves • Showed the successful production as well as the electronic and optical evaluation of several elements of the new type of single photon-on-demand source, such as **current quantization** and **Y-splitting** for controlling the electron flux at a quantum level
SQUBIT 2	• Implemented a three-Josephson-junction flux **qubit coupled to** a quantum **oscillator** (a DC SQUID with an attached capacitor) • Achieved reliable **single-qubit** operation with the **quantronium** charge-phase qubit • **Coupled two flux qubits**, showing conditional spectroscopy as well as conditional excitation and manipulation of 4-level systems.
TOPQIP	• Analysed the **robustness** of **geometric phases** in systems driven by quantized **decohering fields** • Proposed generalized **refocusing schemes** for eliminating the effects of dissipation from geometrical and topological quantum gates, • Devised several schemes for **physical implementations** of **geometric** and **topological** quantum gates

Table: Summary description of the main achievements during 2004 of each of the reviewed projects, and their relation to the FET-QIPC 2001 Call challenges

Please find below the reviewers comments for each project:

ACQP

The core of the project is the manipulation of cold atoms. ACQP builds on an earlier project, ACQUIRE, and especially on the tool box for manipulating atoms. ACPQ aims to use the robust control of neutral atoms by electromagnetic fields to build a simple quantum processor and to achieve single qubit manipulation. The project seems to be making progress in line with plans, and the more recent work has refined its directions. There is some high quality science within the project, and this is pointing to further opportunities. In particular, ACQP has managed to eliminate create conductors of a quality sufficient to avoid the problems of spatial fluctuations of the magnetic field. The ultra smooth films may have wider applications. The Deliverables are broadly in line with plans. Some components have been dropped because of technical issues, e.g., the microsphere resonator. Other components have gone especially well, e.g., the new fibre cavity is a very practical method based on a net idea. The imaging methods using CCD look very promising. It is likely that there will be new insights on atom/surface interactions, and the project looks as though it is getting close to single atom observations.

The objectives of the project remain closely in line with those originally proposed. The objectives of IST2002 - VI.2.1 Quantum Information Processing and Communication (QIPC) are to develop novel systems and techniques for information processing and transmission by exploiting the properties of quantum mechanical operations. ACQP addresses a specific medium-term goal, namely the development of elementary scaleable quantum processors, and also associated challenges such as the control of decoherence and, to a lesser extent, the development of methods for quantum information storage, retrieval and intermediate read-out.

ATESIT

ATESIT is focused on the exploration of the power of entanglement (one of the fundamental resources for quantum information processing and computing) in optical states, with the goal of implementing novel entanglement generation schemes and demonstrating practical experiments like quantum teleportation. Many interesting issues have been tackled since the beginning of the project, in August 2001, with a steady progress towards the final goal. Several tools to implement QIPC were produced. The development of an ultrabright source allowed generating photons that are polarization entangled over the entire emission cone. An additional entanglement in momentum has been demonstrated in the past year. Hyperentangled photon states (that is, entangled both in polarization and in orbital angular momentum) were produced following a novel approach that exploits micromachined spiral phase-plates. The practical usefulness of such states for quantum information processing has being currently studied. Much effort was spent on developing ideas of quantum cloning of qubits and its use as a universal quantum computational operation. By means of a quantum injected optical parametric amplifier developed in the previous years, experimental optimal cloning of one-to-two and one-to-three qubits was demonstrated in 2004. Active teleportation and non locality experiments were performed during the whole period. This experimental activity was supported by intense theoretical work, comprising a general classification of Bell's states, schemes for active teleportation and error correction techniques.

The activity of ATESIT is mainly on track following the original plan. The only delay is in the development of a single-photon detector with high quantum efficiency. This is a very challenging task that has been pursued by many groups working in this field and would be of utmost interest worldwide. ATESIT fulfils all the requirements set by the QIPC program regarding the problems addressed, the value of results, and the balance of experimental and theoretical research.

EDIQIP

EDIQUIP covers an important range of theoretical QI theory with strong emphasis on the effects of imperfect operating conditions due to couplings with environment and unwanted extra couplings of Q-bits. As a central tool they use a numerical approach to simulate quantum algorithms with a small number of Qbits on a faulty processor. This task is of large importance for practical implementations of QIPC as the number of the simulated Qbits (20-30) still is significantly larger as experimentally achieved. As errors and imperfections are unavoidable in practise, the usefulness of QC depends on the way these systems behave under non ideal conditions with noise. The simulations and calculations carried out within this project give important bounds on the required gate fidelities, Q-bit lifetimes and tolerable gate errors. In particular the scaling of the error with the system size is of central importance for any practical implementation as well as testing the efficiency of error correction for particular quantum algorithms.

The consortium has produced a number of important new scientific results in this respect. As an important claim they demonstrated that static imperfections are significantly more detrimental to quantum computers than random errors. For the concrete example of the Grover algorithm they derived heuristic law for the maximum tolerable error as a function of Qbit and gate number where the algorithm still works. Less stringent requirements were found for the maximum tolerable random gate error, which scales polynomially with the number of involved Qbits. Hence standard error correction can be applied easily. As a second important result they demonstrated that the effect of static errors can be effectively reduced to the amount of random errors by a newly invented technique called PAREC (Pauli Random Error Correction). Here frequent random exchange of the computational basis states a using single Qbit flip distribute the static errors among the various Qbits and effectively renders them random errors. This certainly will have to be implemented in systems with not too small static errors.

In general an efficient and general quantum simulator including errors has much wider application perspectives within QIPC in general and in particular when the first few Qbit systems will be experimentally operational. As some extra ideas the consortium discussed quantum storage of classical information as a neat idea, which might have some exploitation perspectives for one time readable data (quantum MP3) as well as simulation of classical equations on quantum computers.

ESQUIRE

The ESQUIRE project targets the theoretical and experimental implementation of a few-Qbit quantum processor using rare earth ions in an ionic host matrix material. The Qbits are formed from hyperfine ground states of spectroscopically selected sub-ensembles of ions. They have been shown to possess coherence times in a range up to milliseconds. The gate interactions are mediated by changes in static electric dipole couplings following excitation into higher-lying electronic states of the ions, which makes gate operations possible on a few µs scale. Readout is performed directly by optical fluorescence. As a first step, the consortium has demonstrated the preparation and selective readout of several ensemble Q-bits using one probe by spectral hole burning with optimized tailored pulses. Subsequent frequency-selective addressing of these Qbits enabled tens of successive Q-bit inversions, losing only a small fraction of the ensemble. As their major recent achievement the partners achieved the preparation of suitable sub-ensemble of ion pairs with the desired interionic coupling to do gate operations. This should directly pave the road to implementation of a CNOT gate. Theoretical work in the project was successful in identifying some highly optimized pulse shapes to improve Qbit selection and gate operations in speed and efficiency. The scalability of the present scheme is less obvious, and success will strongly depend on advances on the side of material development and improvements of readout technology. Several promising ideas, like using significantly higher doping levels or special read ions, have been proposed theoretically and are being investigated in the consortium. Considering the rather limited total research effort so far put into this QC implementation, the approach has already advanced quite far. It seems to have good prospects for use as quantum memory and perhaps also as small quantum processor.

The objectives of the project remain closely in line with those originally proposed. The objectives of IST2002-VI.2.1 Quantum Information Processing and Communication (QIPC) are to develop novel systems and techniques for information processing and transmission by exploiting the properties of quantum mechanical operations. ESQUIRE addresses a specific medium-term goal, namely the development of elementary scaleable quantum processors, and associated challenges such as the control of decoherence and the development of methods for quantum information storage, and retrieval.

PROSECCO

This entirely theoretical project intends to study small scale distributed quantum computations in accomplishing tasks which could not securely be implemented classically. It fits perfectly into the FET QIPC program: Distributed quantum computation tries to combine quantum computation and quantum communication. Typically such tasks are defined by certain rules and the solutions by certain protocols. This is a small, but nevertheless rather inhomogeneous consortium. Even without intensive collaborations between the 4 different partners, the theoretical results are quite impressive. In the information theoretical part of the work, a large fraction of the activities have been concentrated on further analysis of security aspects within various protocols. In the physics part of the work, the scaling behaviour of multi-partite states (graph states) has been reported. Most of the activities include some sort of optimisation procedure. The partners of this project have been performing well during the first two years. Most of the objectives have been achieved.

QGATES

QGATES aims to realise multiple qubit quantum gates with individually-addressable trapped ions, trapped atoms and (optical/microwave) cavity QED systems, and to characterise their fidelity in the context of of a possible scalable quantum processor. The project is substantial, with 14 partners, covering approaches based on trapped ions, neutral atoms, Bose Einstein condensates, and cavity QED. QGATES has met most of its second year milestones with several success stories from the ion processor and the neutral atom processor subgroups, and has exceeded its milestones in some cases. There is more evidence of unity and beneficial cross-project interaction than last year, with good signs of linkage within each project sector (e.g., ions, atoms). It would still be fair to say that these sectors remain largely parallel enterprises but, since this is giving rise to constructive tensions, this is no bad thing. The strong theory component makes a valuable contribution to unifying the project. Key results for ion systems were obtained by the UIBKEX partner, who showed quantum teleportation of ion states, the realization of three-ion entangled states, and the observation of a 20 second entanglement lifetime. Several groups made advances in the use of photoionisation for trap loading. Further activities focused on the ground state cooling and the coherent manipulation. For neutral atom systems, the Hinds group showed excellent progress with BEC-loading of microtraps and their study and understanding of decoherence processes by surfaces. Similar progress was found from EKUT with BECs in optical lattices. There were spectacular results from UBonn with the manipulation of single atoms in a five-atom string in a dipole trap. There was also good progress towards single atom trapping by CNRS/IO. For Cavity QED, the most important results from optical cavities were the demonstration of long term (90 minutes) emission of single photons and many-photon interference effects by both MPQ groups. The theory component includes extremely diversified activities across areas related to all experimental activities. There is much enterprising science. The project team is clearly at the leading edge, with QGATES teams among the world leaders in a very substantial field. They are in good contact with competing teams and with new developments.

The objectives of the project remain closely in line with those originally proposed. The objectives of IST2002-VI.2.1 Quantum Information Processing and Communication (QIPC) are to develop novel systems and techniques for information processing and transmission by exploiting the properties of quantum mechanical operations. QUGATES addresses a specific medium-term goal, namely the development of elementary scaleable quantum processors, and associated challenges such as the control of decoherence and the development of methods for quantum information storage, and retrieval.

QIPD-DF-ROSES

The objective of QIPDDF-ROSES was to develop an elementary quantum computing device using Group V endohedral fullerenes. The project aimed at demonstrating few-qubit quantum information processing using an efficient single electron spin readout technology, that should have been developed during the project. In particular, the focus was on single molecule spectroscopy, STM-ESR and single fullerene transistors as means of reading out the spin state of the endohedral electrons. Only the first of those approaches proved to have a future potential for spin read-out applications.

The work plan was very diversified for the relatively short duration (two years) of the project. The consortium managed to achieve several goals, doing work at the state-of-the-art forefront in this and related fields. The experimental work is noteworthy and of high standards, both in physics and chemistry. Some interesting results were achieved during the two years of activity, and several experimental difficulties were tackled and often solved. The primary objective of the project, i.e. "to develop single qubit readout for solid-state spin based quantum information processing", in particular "to develop single spin detection for a molecular quantum information processor" was partially reached, and some interesting results on the road towards that goal were achieved. The results obtained may have a direct impact for endohedral research and ESR spectroscopy at large. Possible high impact results are definitely those concerning the production of endohedrals, the single molecule spectroscopy and the realization (with further refinements) of the ESR microresonator. There was a reasonably good level of cooperation among the experimental groups.

The objectives of IST2002 - VI.2.1 Quantum Information Processing and Communication (QIPC) are to develop novel systems and techniques for information processing and transmission by exploiting the properties of quantum mechanical operations. The QIPDDF-ROSES project has addressed several issues along those lines, but the results described in the final report do not allow to assess any direct impact for the (near future) realization of an elementary quantum processor. In particular, a mechanism for the read-out of a single molecule could not be realized, which made it impossible to tackle genuinely quantum information related issues, such as the manipulation of single qubits.

QUPRODIS

QUPRODIS is a fully theoretical theoretical project focusing on quantum information processing in distributed quantum systems. The consortium is made up of 15 partners (not all European), and deals with entanglement and correlations in distributed quantum systems and issues of statistical physics, lattice models, modelling of nanomechanical systems and renormalization group applications. This broad and very diversified activity is organized in three interrelated Focus Groups: FG1 Characterization, FG2 Manipulation, and FG3 Implementation, aiming at three Milestones: analysis of lattice models in statistical mechanics (Milestone 1), the graph-theoretical analysis aiming at defining measures for multi-partite entanglement (Milestone 2) and the theory of quantum cellular automata (Milestone 3).

During the last year, the number of publications in peer-reviewed journals has been impressive, with a number of articles published in the Physical Review Letters. The overall research activity has had an impact on other theoretical activities worldwide. This has enabled the consortium to play a significant role, also in relation to other competitive and dynamical groups in the United States, Canada, Singapore and China. The tendency of the partners to work alone, remarked in the first review, remains but it did not prevent the achievement of important results.

Since the beginning of the project, new ideas have emerged in connection with entanglement and phase transitions (in particular during the first year of activity), and with the so-called graph states. The only major difference with the original work plan is in the third milestone, originally devoted to cellular automata/neural networks and now mostly replaced by new computing schemes in optical lattices and nanoelectromechanical systems.

Overall, the project fits well the objectives of QIPC, in the effort to develop novel systems for information processing and transmission, exploiting the properties of quantum mechanical operations and new quantum algorithms. The work done is undoubtedly at the state-of-the-art in several theoretical fields, providing a benchmark for possible future applications. The consortium has a high visibility due to the large number of publications and talks.

RESQ

The achievements of this project during its second year are manifestly outstanding. Substantial progress in many branches of quantum information theory is backed by a remarkable publication list. A few examples of the results obtained by the consortium are ideas on non-local machines, security for string commitment, development of the powerful tool of projected entangled pairs, distributed computing, quantum query complexity and the equivalence of adiabatic and standard quantum computation. Cooperation among the members of the project is large and particularly interesting since the partners belong to different scientific communities.

The project is contributing to a broad range of theoretical topics of quantum information theory with partners from physics, mathematics, statistics and computer science with a strong emphasis on fundamental theoretical concepts. The consortium has produced an extraordinary amount of highest level scientific results, most of them published in high impact journals or presented at top level conferences. The results are largely in the frontline of quantum information theory and setting the direction for future research in the field as well as bridging gaps between the different scientific communities involved in quantum information.

The objectives of the project at this point slightly differ from those in the original proposal. A remarkable case is the proposal of projective entangled pairs as a tool to study many-particle quantum systems. These emerging set of ideas is receiving enormous attention within the quantum information and condensed matter communities. The departure from some of the original goals is justified and welcome in this theoretical, rapidly evolving field since the partners are actually defining the lines of research that most of the groups in Europe are pursuing.

RESQ remains a theoretical project with the highest standards. It does fit the FET QIPC program in many respects. It is worth emphasizing the role this project is playing in bringing contacts and, to some extend, merging the quantum information and computer science communities. The increasing number of collaborations stands as the best tool to bridge cultural gaps and cross-feed both communities. A second and equally relevant outcome of the project is the large number of Ph.D. students well trained in an open minded consortium, which is definitely necessary for the future of quantum information.

RAMBOQ

Since the beginning in 2003, RAMBOQ collected an impressive series of results in the development of technologies and novel schemes to implement quantum computing and quantum communication using conditional linear optical logic. The optical approach has been historically the first one demonstrating quantum effects in reality and all members of the RAMBOQ team have contributed a great deal to the progress of quantum information efforts in Europe. Another advantage of this approach is that linear optics is based on a well established technology, with most elements available "off-the-shelf", and, thanks to the high visibility of the interference effects, error rates are expected to be low. Scalable gates based on linear optics, then, are expected to be more easily realizable, although at the price of an increasing structural complexity. RAMBOQ is trying to build both the technological and the theoretical grounds for such an achievement. At the end of the first year, RAMBOQ had fabricated an efficient single photon source based on a quantum dot, implemented a non-linear shift gate and envisaged a scheme for a two qubti gate (a Conditional Sign Shift). After that, the project proceeded on this line, demonstrating single photon interference using the quantum dot source, implementing a non destructive C-NOT gate with a feed-forward scheme, making experiments of long distance teleportation and entanglement swapping, not only in the lab but also in real world environment.

The efforts in the development of novel sources and detectors address two major bottlenecks of optical approach in quantum information processing. A significant progress in this direction demonstrated by the leading industrial partner on the project creates reasonable hope that the next generation of optical quantum gates and circuits will be much more efficient and reliable due to extensive use of single-photon on-demand sources and high quantum efficiency photon-counting detectors. Several physical implementations of entangled-photon sources demonstrated during the second year created solid foundation for building successful quantum communication devices suitable for both visible and the infrared areas of optical spectrum.

The project is fitting very well the objectives of QIPC. It is developing new schemes and algorithms for quantum information, it is implementing these ideas in real physical systems and is exploiting all this in practical demonstrations of the power of QIPC. An example of this latter point is the first worldwide realization of a bank transfer via entanglement cryptography in the city of Vienna.

SAWPHOTON

The SAWPHOTON project concentrated on the development of a novel single photon source based on electrical injection for quantum information processing, and, in particular, for quantum cryptography.

The physical conception of the device is fresh and interesting: it is basically made up of four main basic components, that constitute together a nanocircuit: a transducer that produces SAWs (surface acoustic waves) in the GHz frequency range; a quantum point contact providing the desired lateral confinement of the acoustic wave and enabling the transport of electrons at the SAW frequency (once and if the amplitude of the SAW is optimised); a lateral p-n junction in a high quality quantum well layer for which the radiative efficiency should be optimal (say, close to 100% at a temperature of a few K); a Y splitter acting as an electron dumper when the rate of the electrons approaching the p-n junction is higher than the reciprocal recombination time between electrons and holes. Clearly, the realization and performance of such a device heavily depends on the very ability to successfully assemble the different components.

The members of the consortium approached this challenging task by proposing a number of interesting technological solutions some of which were demonstrated during the course of the project.

Several interesting ideas were born and/or investigated within the consortium, such as the development of lateral p-n junctions, the alternative designs of the Y-branch, the SAW current division within the Y-branch [although not with single electrons], the characterization of some of the photon sources, the very problem of interfacing quantum electronics and quantum photonics.

Overall, this has been an example of good cooperative research efforts between world leading research teams. The result is a very positive cross fertilisation and stimulating development for all the members. The project partners are among the leaders in this research field, delivering a state of the art performance at every next step.

The optical approach continues to have the leadership in the quality of quantum information processing, providing a benchmark in low decoherence performance for other physical approaches. The first demonstration of quantum cryptography has clearly demonstrated that this rapidly developing quantum technology would definitely benefit from the practical realization of such a source of single photons on demand.

The project results have positioned all participating groups at the first tier of international research efforts in optical quantum information processing. The methodology and technology developed by the consortium (materials growth techniques, nanofabrication methods, and photon detection techniques) might be relevant for future electronics and optoelectronics.

SQUBIT 2

The project aims to manipulate quantum information using superconducting qubits. In particular, it aims (a) to demonstrate the reliable operation of individual qubits (whether charge-phase or flux) and (b) to show how more than one qubit can be linked effectively. It has had some significant successes, noted below, and is broadly on track with its plan. The project is clearly at the leading edge worldwide, with strong scientific links to other leading teams in Japan and North America. It has demonstrated successfully the reliable operation of single qubits and some of the logic operations. Issues were addressed in depth, and that theory (such as the analysis of the effective exploitation of the “magic point”, and also the analysis of the noise and the so-called two level systems). Success in operation of two coupled qubits has been confirmed for some of the possible realisations. Particularly interesting is the idea of coupling flux qubits to a harmonic oscillator (the oscillator here being a DC SQUID with an attached capacitor) in a way that may enable scalability and which allows considerable flexibility. In areas (happily few) where there are potential difficulties (e.g., in the contrast available with switchable couplings), the project is clearly taking a thoughtful and appropriate approach to progress. There appears to be very effective collaboration within a well-run project. There is good complementarity between the teams, and there is a useful natural tension because of the several forms of qubit and the fact that the choice between them is still open. There is much good work. In addition to the team’s own highlight (coupling qubit and harmonic oscillator), I was impressed by some of the work on noise and by the general evident understanding of underlying scientific issues and their implications.

The objectives of the project remain closely in line with those originally proposed.

The objectives of IST2002-VI.2.1 Quantum Information Processing and Communication (QIPC) are to develop novel systems and techniques for information processing and transmission by exploiting the properties of quantum mechanical operations. SQUBIT2 addresses a specific medium-term goal, namely the development of elementary scaleable quantum processors, and associated challenges such as the control of decoherence and the development of methods for quantum information storage, and retrieval.

TOPQIP

The achievements of this project during its second year are very positive. The research done by the partners has brought progress to control geometrical and topological phases in quantum systems, ranging from ion traps to solid state systems and cold gases. The results are published in highly ranked journals and properly disseminated in conferences, so that the visibility of the consortium is manifest.

The project retains a long-term interest due to the promise of robustness attached to the representation of qubits though geometrical and topological phases. The fact that the geometrical phases are less robust but more realizable than the topological ones changes the spirit of the research, the former needing some down-to-earth specific analysis while the latter retains its visionary character. The project is progressing well along this main direction, producing results of relevance both at a theoretical level as well as more focused on specific physical systems.

The objectives of the project at this point slightly differ from those in the original proposal. An understandable shift has been produced to forcefully study geometrical, rather than topological, phases. The research in the consortium should further moved to more applied examples of geometrical phase control. It is though important, that the consortium still maintains long-term research on topological phases.

TOPQIP fits perfectly the FET QIPC program. It provides an example of focused research devoted to an emerging field, still not matured for fully experimental realization, but of manifest long-term interest. The project has also motivated the union of efforts from different countries along its goals. The outcome of the project should encourage experimental analysis of systems where the control of quantum phases is more likely.