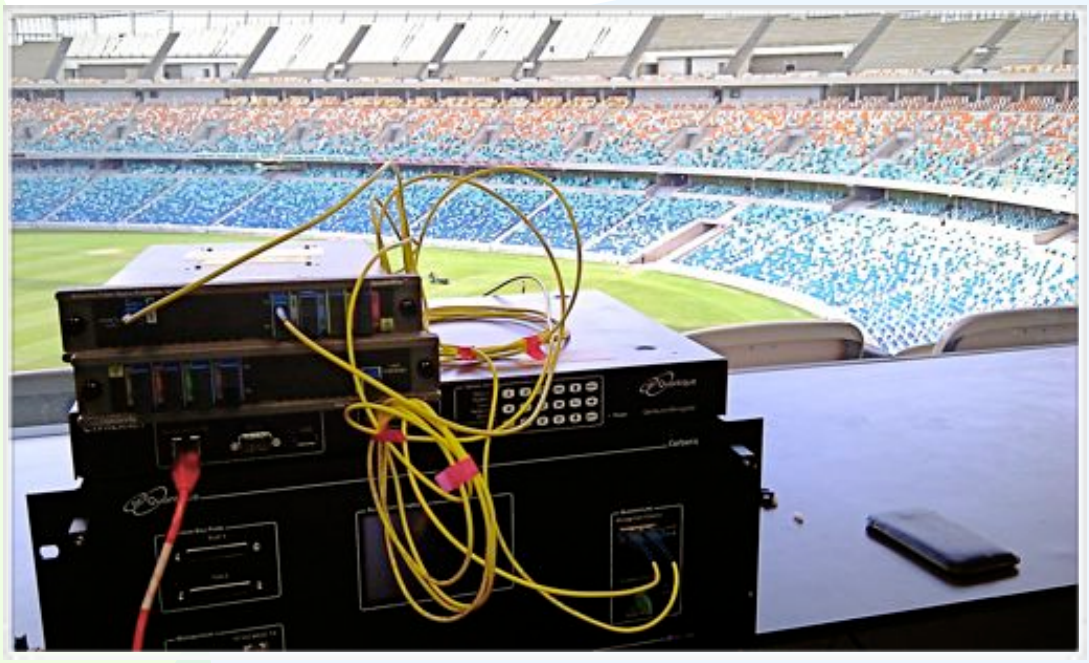
C E N T R E F O R Q U A N T U M
T E C H N O L O G Y

A Research Group of UKZN

ANNUAL REPORT 2010



UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

CENTRE FOR Quantum TECHNOLOGY

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Photos by: Charles Freeman, Abdul Mirza, Sejal Desai and Mhlambululi Mafu



Executive Report



The Centre for Quantum Technology (CQT), a Research Group in the School of Physics at the University of KwaZulu-Natal, began its operations in 2006 with an ambitious plan to foster research and development in the field of Quantum Information Processing and Communication (QIPC). The vision was to attract students to an exciting inter-disciplinary field of research and technology, to train them in a world-class research and development institute and facilitate the establishment of a sustainable quantum technology industry. This would provide opportunities for skilled individuals to engage their expertise and transform local knowledge pools into focussed, innovative solutions.

The year 2010 marked the beginning of the fruition of this vision with the formalization of QZN Technology (Pty) Ltd, a commercial vehicle for the research and development output at the CQT, and preliminary developments around a national, intra-disciplinary research facility in applied QIPC. Together with the CQT, these two structures will provide a sustainable capacity in quantum innovation for South Africa to leverage the upcoming opportunities in the information technology industry of the 21st Century.

Undoubtedly the highlight of 2010 for the CQT was the deployment of quantum-secured communication solution at the Moses Mabhida Stadium during the 2010 FIFA World Cup™. This project has catapulted South Africa into the global race of QPIC. The European Union and the Scientific American (Japan) have recognized this project as a major milestone towards the market acceptance of QIPC.

In the next 5 to 10 years, it is expected that further quantum-powered technology such as atomic clocks, quantum games, optical storage, biomedical imaging and simulation will be introduced to the market. In this period, the worldwide market for quantum-powered products is expected to exceed US$ 70 billion p.a., with quantum-related services likely to become of comparable size (Corker et al., 2005). The forecast is that soon a new QIPC technology industry will reshape the global ICT sector. However, the challenges associated to this pre-emptive technology require prior research and development. Under the 6th Framework Programme, the European Union has invested €38 million in setting up a QIPC cluster, while the USA invests almost €75 million a year in QIPC (F. Rebufat, 2008). The Australian Government has recently budgeted AUS$ 50 million for the next 7 years towards the development of quantum technology (http://www.arc.gov.au/).

The American Research Council has declared optics as the technology of the 21st century. In contrast, the famous physicist, Michael Berry, has stated that the 21st Century will be shaped by quantum physics, as did electrodynamics shape the 20th Century (http://www.gap-optique.unige.ch). The CQT is positioned at the crossroad of these two revolutionary technologies. It is of strategic interest that South Africa supports development of this local knowledge capacity to ensure a global market share in these emerging markets.

Francesco Petruccione

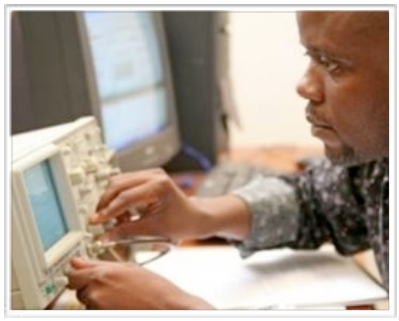
CQT at a Glance

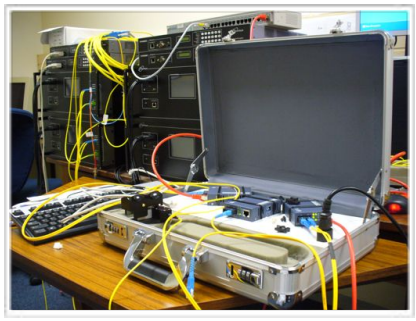
Quantum Information Processing and Communication (QIPC) is an emerging technology with the potential of reshaping everyday life. The convergence of the principles of quantum physics into the framework of information science opens new avenues that are inconceivable with conventional technologies.

Research in quantum technology at UKZN started in 2004 with the appointment of Prof. Francesco Petruccione as a Professor of Theoretical Physics and the establishment of a proto-Centre, the Quantum Research Group (QRG). In the last six years, Prof. Petruccione has significantly strengthened the QRG and placed South Africa on the global map of QIPC. In 2005, the Group was awarded a R 10 million grant from the Innovation Fund and, in 2007, the QRG was responsible for the recognition of QIPC as a National Research Niche Area within the Institutional Research Development Programme. In the same year Prof. Petruccione was granted a South African Research Chair for Quantum Information Processing and Communication.

Today we know that the technological manipulation of information is limited only by the laws of physics. Information can therefore be characterized, quantified and processed using the basic rules of quantum mechanics . Exploiting some of the fundamental features of the quantum world, i. e. the superposition principle and the Heisenberg uncertainty relation, QIPC enables new and exciting possibilities, a revolutionary new computer paradigm that will allow us to build computers capable of solving problems that can not be solved today. At present quantum communication is the most advanced technology in QIPC. It is driven by quantum encryption or, more correctly, Quantum Key Distribution (QKD): a secure method of generating encryption keys between distant parties for the transfer of confidential information. This forms the bases for inviolable global communication networks.







Open Quantum Systems

The miniaturization of technological devices necessitates the manipulation of objects at the nanoscale level at which coherent quantum mechanical processes begin to dominate the physical properties.

The unavoidable interaction of these systems with their environment gives rise to dissipative mechanisms and a strong loss of quantum coherence, i.e. decoherence. Since perfect isolation of quantum systems is not possible, it is of central importance to incorporate the methods and tools of the theory of quantum systems in the exploration of quantum technologies. The Centre has contributed to the development of the theory of open quantum systems, which is at the basis of recent quantum information technological applications.

Quantum Photonics

A key concern in optical quantum information processing is the generation and detection of single photons. The Centre is therefore developing single photon sources and detectors. Defects in diamonds provide an effective means of generating single photons on demand together with being promising candidates for a solid state implementation of quantum computing while pseudo-single photons at telecommunication frequencies are achieved through attenuated laser pulses.

Photon detectors and other photonic manipulative devices are also researched and developed as part of this programme.

Quantum Information Processing

Quantum information processing is a rapidly growing field of science that exploits the laws of quantum mechanics to store, process and communicate information. The fundamental extension of information theory arises in the encoding process and the data carrier. The fundamental unit of quantum information processing is the qubit, which is a two-level quantum mechanical system. Each data bit is physically encoded within a qubit enhancing the manipulation of information to include quantum physical properties. Whereas the classical bit can have two values, 0 and 1, the qubit can be in a superposition of both thereby exponentially increases the opportunity for data processing. In order to study quantum effects and control quantum systems, the Centre is developing techniques to monitor the dynamics of individual quantum systems in real time. Further research is focussed towards coherent control and error correction.

As a first fundamental milestone, the Centre has cooled a cloud of Rubidium 87 atoms to temperatures of a few micro-Kelvin. This is the first Magneto-Optical Trap realised on the African continent, and has placed UKZN on the global map of niche institutions involved in the research of ultra-cold matter and Bose-Einstein condensation. It is possible to trap ultra-cold atoms in periodic potentials made by laser light in what is called optical lattices. This is one of the most promising systems for exploring quantum information processing. The atoms in the optical lattice can be used as a quantum register in a quantum computer.

Quantum Communication

Quantum communication provides a method of theoretically secure data transfer. More commonly known as Quantum Key Distribution (QKD), it uses quantum theory for the secure distribution of encryption keys. The Centre is developing a QKD system as part of a complete secure communication solution. Quantum networking provides a next generation solution towards efficient quantum communication infrastructure. This research programme focusses on improving the offering and integration of quantum communication systems into currently deployed ICT infrastructure.

The QuantumCity initiative was developed, in partnership with the eThekwini Municipality, to showcase the feasibility of quantum cryptography in a commercial environment for extended periods of time. The initiative saw the deployment of a quantum-secured communication network over strategic nodes of the eThekwini Municipality's fibre infrastructure. Following from the QuantumCity initiative, the City of Durban and the Centre for Quantum Technology again partnered together to provide unprecedented communication security to Durban's 2010 FIFA World Cup™ operations.



Personnel



Professor Francesco Petruccione studied Physics at the University of Freiburg i. Br. and received his PhD in 1988. He received his 'Habilitation' (Dr. rer. nat. habil.) from the same University in 1994 and worked there as Associate Professor of Theoretical Physics until 2003. In 2004 he was appointed Professor of Theoretical Physics at the University of KwaZulu-Natal. In 2005 he was awarded an Innovation Fund grant to set up a Centre for Quantum Technology. In 2007 he was granted a South African Research Chair for Quantum Information Processing and Communication. Since March 2008 he is a member of the Board of the UKZN Innovation Company. Prof. Petruccione has published more than 90 papers in refereed journals. He is the co-author of a monograph on The Theory of Open Quantum Systems, that was published in 2002, reprinted as paperback in 2007, and has been translated into Russian. He is the editor of several proceedings volumes and of special editions of scientific Journals. Prof. Petruccione is a member of the Editorial Board of the prestigious Journal Open Systems and Information Dynamics. He has been invited to deliver more than 50 talks. He is a Director of QZN Technology (Pty) Ltd.

Professor Erwin Brüning studied Physics, Mathematics and Philosophy at the University of Göttingen. He received his Dr. rer. nat. (Göttingen) in 1971 and his Priv. Doz. (in Theoretical Physics, University of Bielefeld) in 1978. He served as a university professor in France for Applied Mathematics and Applications of Mathematics. Prof. Brüning is the recipient of three prestigious research fellowships (JSPS, DFG, Max Kade) and co-author of 4 books. He stands on the editorial committee for Applicable Analysis (Associate Editor) and Advances in Nonlinear Variational Inequalities (Co-Editor). He has been invited to over 20 conferences as guest professor and research fellow and further presented more than 65 seminar talks.



Professor Martin Porrmann studied Physics and Mathematics Freie University Berlin, the University of Hamburg and at the Georg-August-Universität Göttingen. He was awarded the doctorate in natural sciences in January 2000. He moved to the II Institute for Theoretical Physics in Hamburg to take up a postdoc position within a research project funded by the DFG (national science foundation in Germany). From 2006 to the beginning of 2008 he worked as a lecturer of mathematics at the University of Applied Sciences in Hamburg. In February 2008 he joined the Quantum Research Group within the School of Physics of the University of KwaZulu-Natal as a postdoctoral fellow. One year later, starting in February 2009, he was appointed Associate Professor at the University of KwaZulu-Natal. Since March 2009 he is an associate member of the National Institute for Theoretical Physics of South Africa.



Professor Thomas Konrad studied Physics and Philosophy at the University of Tüebingen 1987-1995. He furthered his studies in quantum field theory and elementary particle physics at Imperial College in London and obtained the Master of Science of the University of London as well as the Diploma of Imperial College. He obtained his PhD in 2003 from the University of Konstanz in Germany with summa cum laude and worked there until 2006. Since 2006 he is employed as Associate Professor at the University of KwaZulu-Natal where he is member of the Quantum Research Group.





Dr. Mervlyn Moodley obtained a BSc, Honours and MSc(cum laude) in physics from the former University of Natal (PMB). He obtained a MSc (in 2000) and PhD (in 2003) from the University of Rhode Island in the United States, in theoretical and computational physics. He thereafter worked as a lecturer in the School of Physics at the University of KwaZulu-Natal(UKZN) before taking up a post-doctoral fellowship under the supervision of Prof. Petruccione. He is currently employed as a lecturer in the School of Physics at UKZN. Dr. Moodley is a SA Association for the Advancement of Science bronze medalist and a recipient of the NRF prestigious scholarship for overseas doctorate. He was also the secondary proposer in securing a grant from the Innovation Fund to establish the Centre for Quantum Technology and is one of the founding members of the Quantum Research Group(QRG) at UKZN.



Dr. Alessandro Sergi obtained his PhD in physics in 1997 from the University of Messina (Italy). Dr. Sergi began working as a postdoctoral researcher in the Departments of Physics at the University of Modena and Rome La Sapienza in Italy, and in the Departments of Chemistry of the University of Toronto (Canada) and Penn State University (USA). He returned to the University of Messina as a Research Associate in March 2005. In August 2007 he joined the School of Physics of the University of KwaZulu-Natal with a position as Senior Lecturer. Shortly after this, he joined the Quantum Research Group. Dr. Sergi has co-authored 29 research publications (being the sole author of 7 papers) and 3 book chapters. Dr. Sergi currently acts as referee for the following journals: Journal of Chemical Physics, Journal of Physics A, Physical Review E, European Physics Journal B, and Physica D.



Dr. Ilya Sinayskiy (Sinaysky) graduated from the Physics and Mathematics School with honors and entered the Faculty of Physics of Samara State University in 1998. In 2003 he graduated from this university with honors and entered the post-graduate school, specializing in laser physics. In 2006 he graduated from the post-graduate school and obtained his PhD degree (candidate of physical and mathematical science). From January 2008 to November 2009 he was a postdoctoral fellow in the Quantum Research Group, School of Physics, University of KwaZulu-Natal. Since December 2009 he is a researcher at the National Institute for Theoretical Physics (KwaZulu-Natal node).

The Centre is continuously growing its student enrollment as human capital development is one of the major goals. The current student participation is outlined below:

NAME	DEGREE	RESEARCH FOCUS	CITIZEN
Dr. Fillipo Giraldi	Post Doc	Open Quantum Systems	Italy
Dr. Anne Ghesquiere	Post Doc	Open Quantum Systems	France
Dr. Suranjana Ghosh	Post Doc	Quantum Communication	India
Dr. Utpal Roy	Post Doc	Quantum Information Processing	India
Dr. Magnus Rehn	Post Doc	Quantum Information Processing	Sweden
Mr Abdul Mirza	PhD Candidate	Quantum Communication	South Africa
Mr Charles Freeman	PhD Candidate	Quantum Photonics	South Africa
Mr Viroshan Naicker	PhD Candidate	Open Quantum Systems	South Africa
Ms Malehlohonolo Semonyo	PhD Candidate	Quantum Information Processing	South Africa
Mr Lucien Mbenza	PhD Candidate	Quantum Photonics	DRC
Mr Pierrot Musumbu	PhD Candidate	Open Quantum Systems	DRC
Mr Ismail Akhalwaya	PhD Candidate	Open Quantum Systems	South Africa
Ms Adriana Marais	PhD Candidate	Quantum Communication	South Africa
Mr Craig Duerrheim	PhD Candidate	Quantum Information Processing	South Africa
Mr Tony Nzundu	PhD Candidate	Open Quantum Systems	DRC
Mr Bheki Zulu	PhD Candidate	Quantum Photonics	South Africa
Mr. Michael Nock	PhD Candidate	Open Quantum Systems	Germany
Mr Davvy Nganga	MSc Student	Quantum Communication	DRC

NAME	DEGREE	RESEARCH FOCUS	CITIZEN
Mr N Pumulo	MSc Student	Quantum Information Processing	Zambia
Mr N Wamunyima	MSc Student	Quantum Information Processing	Zambia
Ms Humairah Bassa	MSc Student	Quantum Information Processing	South Africa
Mr K Garapo	MSc Student	Quantum Information Processing	South Africa
Mr David de la Rey	MSc Student	Quantum Information Processing	South Africa
Mr Mhlambululi Mafu	MSc Student	Quantum Communication	South Africa
Ms Sharmini Pillay	BScHons Student	Quantum Communication	South Africa
Ms. Sharlene-Asia Naicker	BScHons Student	Quantum Information Processing	South Africa
Ms. N.N. Sithomo	BScHons Student	Quantum Communication	South Africa
Mr S Dlamini	BScHons Student	Quantum Information Processing	South Africa



The QuantumStadium

Background

Quantum cryptography is theoretically impossible to compromise and is therefore the safest method of data communication known. However until recently, these systems have serviced only a niche market segment. The CQT has however spearheaded the global adoption of QKD into mainstream ICT infrastructure. As scientists and engineers continue to plough through the associated challenges and the market demands drift towards nanotechnology, the prospects for quantum communication becoming mainstream technology grows. One of the primary applications suited for current quantum communication technology is securing building to their offsite recovery and control centres. This has been the primary application in both the QuantumCity initiative and the QuantumStadium project.

The Durban QuantumCity initiative is a quantum communication network that runs along the fibre infrastructure of the eThekwini Municipality. In partnership with the eThekwini Municipality, the Innovation Fund and UKZN Innovation, the Centre for Quantum Technology, implemented the network in 2008. The network currently secures municipal buildings in the suburbs of Pinetown and Westville. The initiative intends to expand its coverage, converting Durban from a Smart City to the first Quantum City in Africa.



The unveiling of the QuantumStadium project. Left to Right: Mr A. Mirza (CQT), eThekwini Mayor Councillor O. Mlaba, Prof. F. Petruccione (CQT), Minister of Science and Technology Ms N. Pandor, Premier of KZN Dr. Z.L. Mkhize, Prof R. Slotow (UKZN)

The Project

Building on the QuantumCity initiative, the CQT and the eThekwini Municipality again partnered to provide a quantum cryptography security solution to one of the most crucial links of Durban's ICT initiatives during the 2010 FIFA World Cup™. The QuantumStadium project encrypted the link between Durban's Moses Mabhida Stadium and the eThekwini's offsite Joint Operations Centre that housed the South African Police Force, Emergency Services and National Intelligence. The deployed system was similar to that used in the QuantumCity initiative however additional redundancy was added as a safety measure. The quantum communication link secured telephone, internet, video, data and

email traffic traveling across the fibre optic link. This was the first time that quantum cryptography was applied to secure an event of global relevance.



Abdul Mirza, project manger of the QuantumStadium, explains the technology to Minister Pandor.



KZN Premier, Dr. Z Mkhize announces his support for the Centre at QuantumStadium launch.

The project attracted the interest of local and international media as well as the global QIPC research community. The National, Provincial and Local Government demonstrated their interest in this development by participating in the official launch of the QuantumStadium Project on 21 May 2010.

The development of the QuantumStadium project from the proof of concept experiments in a laboratory environment to the fruition of the technology during the 2010 FIFA World Cup™ has demonstrated the ability of the Centre to engineer solutions from inception and support it throughout its innovation cycle. The establishment of a Centre of Competence will further enhance the capacity of the quantum technology industry to develop further such solutions.

The European Commission's Roadmap for Quantum Information Processing and Communication, European Telecommunications Standards Institute and the Scientific American have all recognized this project as a major milestone towards the market readiness of quantum information processing solutions.



Network layout of the QuantumStadium project. Linking the Moses Mabhida Stadium with the offsite recovery centre.

Conferences and Workshops

Quantum Africa 2010

Recent Progress in Theoretical and Experimental Foundations of Quantum Technology

In 2006 the Centre for Quantum Technology hosted a very successful international conference on Quantum Technology in Durban. This was motivation to repeat the conference in 2010. From 20 to 23 September 2010 the Centre for Quantum Technology organised the international conference on Recent Progress in Theoretical and Experimental Foundations of Quantum Technology. The conference was held at the newly reopened Oyster Box Hotel in Umhlanga Rocks. The Conference also started a new cycle of Conferences: The Quantum Africa series of conferences which is planned to take place consecutively in several African countries.

The motivation for this conference is to provide a knowledge base for research in quantum technology in South Africa, with emphasis on quantum cryptography. On the basis of the list of invited and confirmed international speakers, the conference was of great interest to colleagues from around the world. The conference featured many international renowned speakers and experts in quantum information processing, quantum cryptography, quantum optics, ultra-cold atoms, open quantum systems, quantum biology, and other relevant areas of quantum technologies.

The table below lists the invited speakers and their contributions.

INVITED SPEAKER	AFFILIATION	CONTRIBUTION
Prof. Ph. Blanchard	University of Bielefeld, Germany	Decoherence in infinite Bose Quantum Systems
Prof. H. Briegel	University of Innsbruck, Austria	Quantum effects in Biology
Prof. A. Buchleitner	University of Freiburg, Germany	Transport, disorder, and entanglement
Prof. T. Calarco	University of Ulm, Germany	Quantum technology taken to its (speed) limit
Prof. L. Diosi	Research Institute for Particle & Nuclear Physics, Budapest, Hungary	Quantum information loss by frame averaging
Prof. A. Ekert	University of Oxford, UK and National University of Singapore	Less reality, more security
Prof. S. Haroche	College de France & ENS, Paris, France	Manipulation and control of non-classical field states in Cavity QED
Prof. A. Kastberg	University of Nice, France	Quantum information with cold atoms and photons
Sir P. Knight	Imperial College, London, UK	Utilising Coherent Population Trapping for Quantum Technologies
Dr. H. Uys	National Institute of Standards, Boulder, Colorado, USA	Toward spin squeezing of trapped Beryllium ions

The conference was attended by over 50 participants.



Participants of the Quantum Africa 2010 conference at the Oyster Box Hotel (Umhlanga).

Quantum Field Theory on Curved Spacetime: From the Algebraic Approach to Local Covariance

The workshop was organized by Prof. Martin Porrmann and Prof. Francesco Petruccione and was held at UKZN between 23 and 27 August 2010. The invited speakers and their contributions were: Nicola Pinamonti (Rome), Semiclassical Einstein Equations: Existence of Solutions with Relevance in Cosmology; Romeo Brunetti (Trento), From Classical to Quantum Field Theories: Perturbative and Non-Perturbative Aspects; Detlev Buchholz (Göttingen), The Sector Structure of QED. Solving Infrared Problems by Space-Time Truncation; Eric Morfa-Morales (Vienna), Wedge Regions in Curved Spacetimes; Robert M. Wald (Chicago), The Formulation of Quantum Field Theory in Curved Spacetime; Ko Sanders (Göttingen), On the Self-Adjointness of Wick Polynomials in Hadamard Representations; Claudio Dappiaggi (Hamburg), From Local Causal Structures to Local Hadamard States; Valter Moretti (Trento), On the Modular Group of the Free Massive Klein-Gordon Field in Double Cones; Thomas-Paul Hack (Hamburg), Quantum Field Theory on Curved Spacetimes Meets Experiment: Supernova Ia Measurements and Dark Energy; Gandalf Lechner (Vienna), Deformations of Quantum Field Theories.







Non-Markovian Unravellings for Open Quantum Systems

This Research Workshop was organised by Prof. F. Petruccione to address a topical issue of great interest at the moment. Among the participants were Prof. S. Attal (Lyon), who gave an introductory Quantum Noises; Prof. Mark Fannes (Leuven): Entropic bounds for correlated states); Prof. Robert Alicki (Gdansk): A quantum model of almost perfect energy transfer; Dr Rosanna Migliore (Palermo): Dissipative effects on the entanglement dynamics and in Josephson architectures.

Outreach Programmes

National Science Week 2010

The CQT has been actively participating in the activities of the National Science Week. In 2010 three students, Poppy Semonyo, Adriana Marais and Abdul Mirza participated in this outreach programme providing high school learners with insights into the principles and opportunities in QIPC. The events were organized through SAASTA and included a series of talks and lab visits.

Eskom Science Expo

The CQT has also been involved with the standardizing of the judging process at the ESKOM Science Expos. This year, Abdul Mirza was further invited to give a keynote address during the Ugu District Finals. His talk was entitled, 'South Africa's got talent' and focussed on South African homegrown innovations in Science and Technology.

SAASTA Entrepreneurship Programme

The NICLE programme of the NRF focusses on developing learner entrepreneurship. The CQT has again actively participated in many functions and workshops that the programme has conducted throughout the year.

MTN Sciencentre's Round Table Discussion

The MTN Sciencentre hosted a Media Round Table entitled, 'Nanotechnology: Is it really the Technology of the Future' on 10 November 2010. Francesco Petruccione was invited as a keynote speaker at this event as the Head of the CQT, the forerunner in quantum technology in Africa.



Visitors

Research Visits

During the year 2010 several researchers visited the Centre for Quantum Technology to work on joint research projects.

The following table gives an overview of the visiting researchers and their period of stay.

VISITOR	AFFILIATION	TOPIC OF DISCUSSION
Dr C. Pellegrini	University of Lyon, France	Remainder of quantum repeated interactions: the zero temperature case
Mr C. Righy	University of Stellenbosch	Development of laser cooling and magento-optical trapping equipment for ultracold rubidium atoms
Mr T. Latzko	University of Applied Sciences, Koblenz	General – purpose computation on graphics processing units
Prof U. Jaekel	Applied Sciences, Koblenz	Random matrices random correlations and applications to finance
Prof O. Onyejekwe	Florida Institute of Technology, Florida	Green element method (gem) calculation of couette flow and heat transfer involving temperature dependent electrical conductivity and viscosity
Mr V. Naicker	University of Cambridge,	Entropy graph results: The proofs of Zhao,Khn and Lawrenz
Mr K. Mayer	University of Freiburg, Germany	Many-particle quantum walks
Mr M. Christopher	University of Freiburg, Germany	Many-Boson interference
Dr J. Degorre	University of Singapore,	A combinatorial approach to nonlocality
Dr G. Rehali	University of Umea, Sweden	Quantum model for the double optical lattice
Dr S. Paul	University of Umea, Sweden	Cold atoms in an optical lattice: a simple system
Prof J. Paz	University of Buenos Aires, Argentina	An efficient approach to quantum process tomography (theory and experimental)
Prof S. Attal	University of Lyon, France	An introduction to quantum noises
Dr. M. Munsch	CEA Grenoble	Nanophotonics with semiconductor devices

Publications

The Theory of Open Quantum Systems (Russian translation)

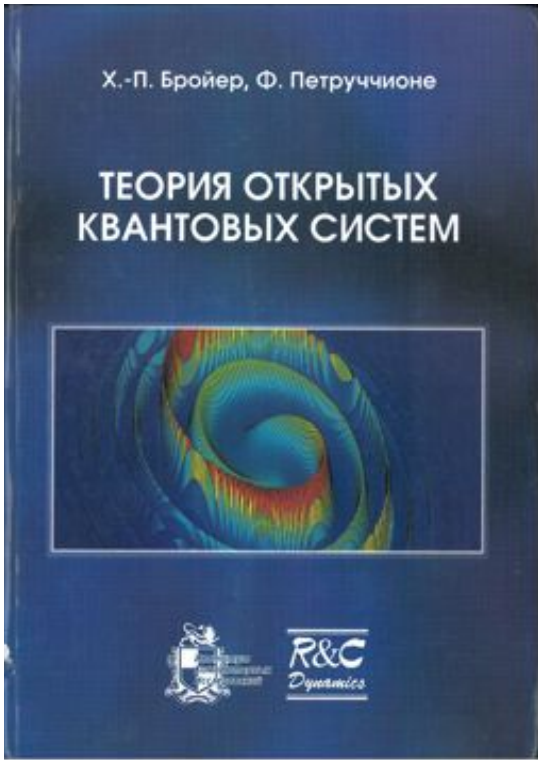
Бройер Х.-П., Петруччионе Ф. Теория открытых квантовых систем / Пер. с англ. под ред. Ю.И. Богданова. - М. - Ижевск: НИЦ "'Регулярная и хаотическая динамика", Иститут компьютерных исследований, 2010. - 824с.

Proceedings of the 18th Chris Engelbrecht Summer School

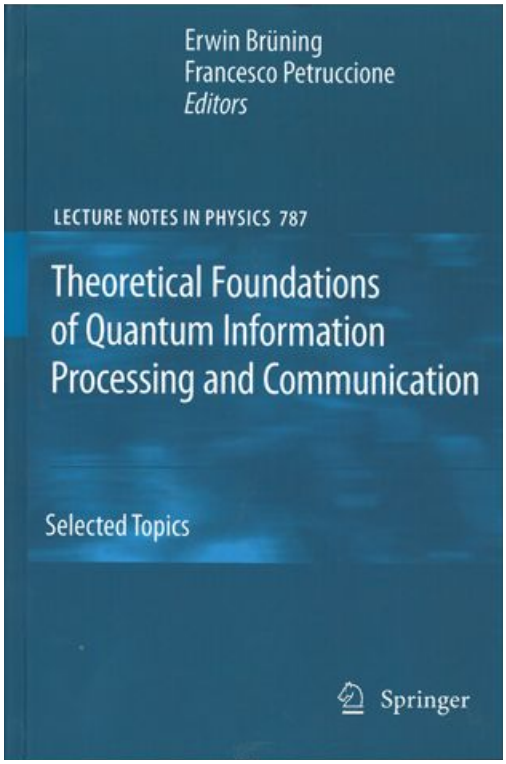
Theoretical Foundations of Quantum Information Processing and Communication: Selected Topics. Lecture Notes of the 18th Chris Engelbrecht Summer School in Theoretical Physics.

Eds. E. Brüning and F. Petruccione. Lecture Notes in Physics 787, Springer, Berlin, Heidelberg (2010). DOI 10.1007/978-3-642-02871-7. ISBN 978-3-642-02870-0

Contributors: M. Fannes, B. Vacchini, R. Alicki, S. Bose, H.-P. Breuer, B. C.Hiesmayr, P. Kok, D. R. Terno.



Russian translation of the monograph "The Theory of Open Quantum Systems"



Proceedings of the 2008 Summer School.

Publications in refereed journals

1. **A Lie symmetry analysis of the Caldeira-Leggett model**. Viroshan Naicker and Francesco Petruccione. Open Systems & Information Dynamics. Volume 17, Number 4, Pages 409-417. Published: December 2010.

   Abstract: An important model in the theory of open quantum systems is the Caldeira- Leggett quantum Brownian motion model for the behaviour of a massive quantum particle weakly interacting with a bath of harmonic oscillators. The model is formulated in terms of a (1 + 2) dimensional partial differential equation (PDE) for the reduced density matrix of the particle. In this paper we analyze this PDE from the perspective of Lie symmetry groups. A Lie point symmetry analysis is performed and a number of canonical reductions are obtained. Of note are new analytic solutions to the model obtained by mapping the model to the linear diffusion equation.

2. **Stochastic Schrodinger equations with coloured noise**. Alberto Brachielli, Clement Pellegrini and Francesco Petruccione. Europhysics Letters. Volume: 91, Article Number: 24001. Published: July 2010.

   Abstract: A natural non-Markovian extension of the theory of white noise quantum trajectories is presented. In order to introduce memory effects in the formalism an Ornstein-Uhlenbeck coloured noise is considered as the output driving process. Under certain conditions a random Hamiltonian evolution is recovered. Moreover, non-Markovian stochastic Schrodinger equations which unravel non-Markovian master equations are derived. As a prototypical example, an harmonic oscillator is considered, able to emit light and with memory terms in the dynamics. The signature of the non-Markovian dynamics is seen in the spectrum of the emitted light.

3. **Quantum-secured communication**. Francesco Petruccione and Abdul Mirza. Quest. Volume: 6, Issue: 2, Pages: 52-55. Published: 2010.

   Abstract: Cryptography has been around for decades. So long in fact, that code breakers abound. Now, quantum physics is providing secure keys to confound the code breakers, as Francesco Petruccione and Abdul Mirza show us.

4. **Realizing long-term quantum cryptography.** Abdul Mirza and Francesco Petruccione. Journal of the Optical Society of America B - Optical Physics. Volume: 27,Issue: 6, Pages: A185-A188. Published June 2010.

   Abstract: We present a set of long-term quantum key distribution (QKD) results from the QuantumCity initiative in Durban, South Africa. Many QKD experimental setups have failed to provide a long-term analysis of QKD systems in commercial environments. Long-term analysis of the stability and performance of these systems is an imperative step towards e market acceptance of QKD technology. The Durban-QuantumCity project intends to develop a multi-user quantum communication network that is currently overlaid on the fiber infrastructure of the eThekwini Municipality. The first phase of this project includes the deployment of a four-node star network. To date, two links have been deployed and one link has run continuously for a number of months. We provide a brief overview of practical implementations of quantum networks and the first set of results from the live data encryption of the QuantumCity project.

5. **A necessary condition for the security of differential-phase-shift quantum key distribution.** Adriana Marais, Thomas Konrad and Francesco Petruccione. Journal of Physics A: mathematical and Theoretical. Volume: 43, Issue: 30, Article Number: 305303. Published 30 July 2010.

   Abstract: A necessary condition for the security of a quantum key distribution protocol is that Bob's measurement is described by non-commuting POVM elements. The differential-phase-shift quantum key distribution protocol is formalized, and this condition is shown to be met.

6. **Monitoring the wave function by time continuous position measurement.** Thomas Konrad, Andreas Rothe, Francesco Petruccione, Lajos Di'osi. New Journal of Physics. Volume: 12, Article Number: 043038. Published: 21 April 2010. (arXiv: quant-ph/0902.2249).

   Abstract: Motivated by the technical requirements of quantum information processing and nanotechnology, the control of individual quantum systems such as single atoms, ions or even photons has become a highly desirable aim. The monitoring of quantum systems-a direct test and in many cases a prerequisite of their control-has been investigated so far only for certain observables such as the position or momentum of quantum particles. Here, we describe a method to monitor in real time the complete state of a quantum particle with unknown initial state moving in a known potential. The method is based on successively updating an estimate by the results of a continuous position measurement. We demonstrate by numerical simulations that even in a chaotic potential tracking the wave function of a particle is possible, and we show with an example that the monitoring scheme appears to be robust against sudden random perturbations.

7. **Sampling of quantum dynamics at long time.** A. Sergi and F. Petruccione. Physical Review E, Volume: 81, Article Number: 032101, Published: 2010.

   Abstract: The principle of energy conservation leads to a generalized choice of transition probability in a piecewise adiabatic representation of quantum(-classical) dynamics. Significant improvement (almost an order of magnitude, depending on the parameters of the calculation) over previous schemes is achieved. Perspectives for theoretical calculations in coherent many-body systems are opened.

8. **'Nonlinear' positive mappings for density matrices.** E. Brüning and F. Petruccione. Physica E, Volume: 42, pages: 436-438, Published: 2010.

   Abstract: In quantum physics one uses density matrices on separable Hilbert spaces for the mathematical description of states. Often it is important to know when the image of a density matrix under a mapping is again a density matrix. We propose some new classes of mappings which map the space of density matrices on one Hilbert space H into the space of density matrices on some other Hilbert space H where H = H naturally is allowed. Such mappings may be 'linear' or 'nonlinear'. In the case of finite dimensional Hilbert spaces we find all mappings of this type.

9. **Random repeated quantum interactions and random invariant states**. I. Nechita · C. Pellegrini. Probab. Theory Relat. Fields, DOI 10.1007/s00440-010-0323-6, Published: 2010.

   Abstract: We consider a generalized model of repeated quantum interactions, where a system H is interacting in a random way with a sequence of independent quantum systems Kn , n ≥ 1. Two types of randomness are studied in detail. One is provided by considering Haar-distributed unitaries to describe each interaction between H and Kn . The other involves random quantum states describing each copy Kn . In the limit of a large number of interactions, we present convergence results for the asymptotic state of H. This is achieved by studying spectral properties of (random) quantum channels which guarantee the existence of unique invariant states. Finally this allows to introduce a new physically motivated ensemble of random density matrices called the asymptotic induced ensemble.

10. **Bulgac-Kusnezov-Nose-Hoover thermostats**. A Sergi, GS Ezra, 10.1103/PhysRevE.81.036705

    Abstract: This paper, we formulate Bulgac-Kusnezov constant temperature dynamics in phase space by means of non-Hamiltonian brackets. Two generalized versions of the dynamics are similarly defined, one where the Bulgac-Kusnezov demons are globally controlled by means of a single additional Nose variable, and another where each demon is coupled to an independent Nose-Hoover thermostat. Numerically stable and efficient measure-preserving time-reversible algorithms are derived in a systematic way for each case. The chaotic properties of the different phase space flows are numerically illustrated through the paradigmatic example of the one-dimensional harmonic oscillator. It is found that, while the simple Bulgac-Kusnezov thermostat is apparently not ergodic, both of the Nose-Hoover controlled dynamics sample the canonical distribution correctly.

11. **Amplitude damping of Laguerre-Gaussian modes**,A. Dudley, M. Nock, T. Konrad, FS Roux, A. Forbes, OPTICS EXPRESS, V 18, 22, 22789-22795, Published: 2010.

    Abstract: We present an amplitude damping channel for Laguerre-Gaussian modes. Our channel is tested experimentally for a Laguerre-Gaussian mode, having an azimuthal index l = 1, illustrating that it decays to a Gaussian mode in good agreement with the theoretical model for amplitude damping. Since we are able to characterize the action of such a channel on orbital angular momentum states, we propose using it to investigate the dynamics of entanglement. (C) 2010 Optical Society of America.

Other Publications

1. **Quantum Key Distribution - A World First for Durban**, A Mirza and F Petruccione, G Lenhart and G Ribordy, Quantum Journal (2010) 11-12

2. **QuantumCity gets quantumStadium**, A Mirza and F Petruccione, Physics Comment, Vol. 2 Iss. 2 (2010) 2-3

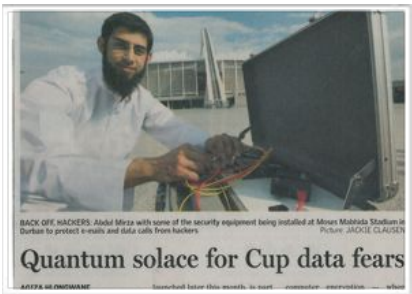
Achievements

Degrees Obtained

1. Graham Daniels, MSc (Physics), Violation of the Bell Inequality using a Neutrino Model, 2010
2. Adriana Marais, MSc (Physics), Security and entanglement in differential-phase-shift quantum key distribution, 2010
3. Lucien Nzuzi Mbenza, MSc (Physics), Development and Testing of an Interferometer for the Characterization of Single Photon Emitters, 2010
4. Nompumelelo Sithomo, BScHons (Physics), Using Physics methods to refine the current methods used in the financial market, 2010

Awards Received

1. Adriana Marais, "Women in Science Fellowship" Award from the Department of Science and Technology


BACK OFF, HACKERS: Abdul Mirza with some of the security equipment being installed at Moses Mabhida Stadium in Durban to protect e-mails and data calls from hackers Picture: JACKIE CLAUSEN

Quantum solace for Cup data fears


FELLOWSHIP AWARD: Physics student to work on renewable energy

UKZN researcher dreams big


The new scientific revolution

CQT in the Media

The Centre for Quantum Technology appeared in the media frequently in 2010

1. Quantum solace for Cup data fears, Sunday Times, 01 May 2010 http://www.timeslive.co.za/sundaytimes/article428965.ece/Quantum-solace-for--Cup- data--fears)
2. Durban stadium gets quantum security, IT Web, 06 May 2010 (http://www.itweb.co.za/index.php?option=com_content&view=article&id=32872:durban-stadium-gets-quantum-security)
3. 2010 quantum security risk is 'academic', IT Web, 20 May 2010 (http://www.itweb.co.za/index.php?option=com_content&view=article&id=33300:2010-quantum-security-risk-is-academic&catid=359)
4. Address by Minister of Science and Technology Naledi Pandor at the launch of the Quantum communication security project, SA Government Information, 21 May 2010 (http://www.info.gov.za/speeches/2010/10052411551002.htm)
5. Quantum Encryption to Secure World Cup Link, FOX Business, 21 May 2010 (http://www.foxbusiness.com/story/markets/industries/finance/quantum-encryption-secure-world-cup-link/)
6. Minister unveils 2010 quantum security, IT Web, 24 May 2010 (http://www.itweb.co.za/index.php?option=com_content&view=article&id=33383:minister-unveils-2010-quantum-security&catid=41&Itemid=160)
7. Durban's high tech stadium, FIFA, 25 May 2010 (http://www.fifa.com/worldcup/news/newsid=1217593/)

8. Encryption kicks off in the quantumStadium, Physics Today, 27 May 2010
   (http://physicsworld.com/blog/2010/05/playing_in_the_quantumstadium.html)

9. Soccer fans get hi-tech link-up, Business Report: Sunday Tribune, 30 May 2010
   (http://www.busrep.co.za/index.php?fArticleId=3951284)

10. FIFA plays ball with tech, too, Business Standard, 12 June 2010
    (http://www.business-standard.com/india/news/fifa-plays-balltech-too/397937/)

11. SCIENCE AND TECHNOLOGY: Quantum leap for Moses Mabhida Stadium, Business Day, 29 June 2010
    (http://www.businessday.co.za/Articles/Content.aspx?id=113179)

12. Quantum security for Durban's computers, Business Day, 07 July 2010
    (http://www.businessday.co.za/Articles/Content.aspx?id=113947)

13. UKZN researcher dreams big, The Witness, 06 September 2010
    (http://www.witness.co.za/index.php?showcontent&global[_id]=46925)

14. The new scientific revolution, The Mercury, 27 October 2010
    (http://www.themercury.co.za/)

15. Kick-off for quantum security, Physics World, July 2010
    (http://physicsworldarchive.iop.org/index.cfm?action=summary&doc=23/07/phwv23i07a1%40pwa-xml&qt=)



Dr Magnus Rehn and Poppy Semonyo explain to the Minister of Science and Technology, Mrs Naledi Pandor, the Director General of the DST, Dr. Phil Mjwara, and the DVC of Teaching and Learning at UKZN, Prof. Renuka Vithal, the progress made by the CQT towards the development of a quantum computer.



Quantum Innovation Industry in South Africa

To afford South Africa a significant global presence within the upcoming nano-ICT revolution, it is imperative that we enhance our nanotechnology capabilities. In order to secure our lead in this global race, a sustainable innovation cycle underpinned by a knowledge driven culture is required. The building blocks for a sustainable knowledge economy are:

- Education,
- Information infrastructure,
- Innovation and
- Economic and institutional infrastructure.

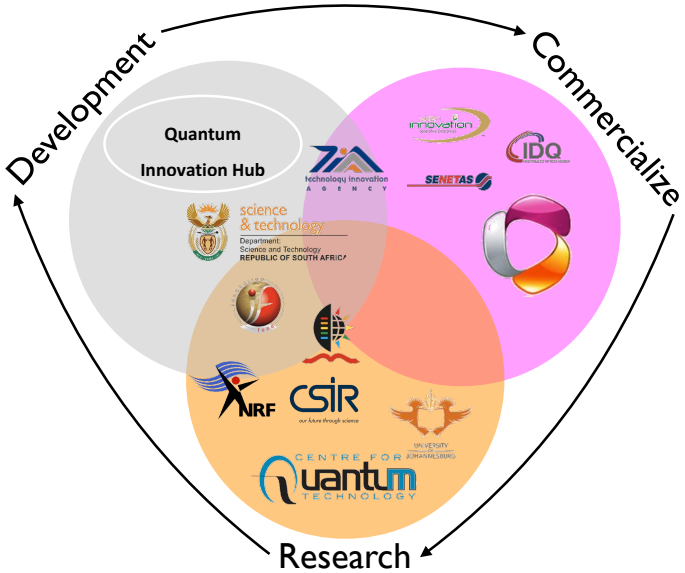
To overcome the innovation chasm, an incubative framework must be established and comprise of three interlinked and mutually supportive processes to support the technology throughout its lifecycle and value chain. The three phases of innovation include research, development and commercialization. Currently the CQT is the only focussed structure in Southern Africa dedicated to QIPC. It has therefore houses all the phases of the innovation framework internally. An expansion of this knowledge infrastructure is, however, required in order to transform our Nation's skills base and capacity for future innovations. The vision for the proposed quantum innovation framework is:

> "through applied research and innovative technologies, to develop and deliver quantum-related products and services that will contribute significantly to creating and retaining a technological skills base in South Africa, able to spin-off new enterprises that will play a meaningful role in South Africa's socio-economic development."

In recent visits to the Centre, both the Minister of Science and Technology, Mrs Naledi Pandor, and the Premier of KwaZulu-Natal, Dr Zweli Mkhize, expressed their enthusiasm and support for the research and commercialization of this technology.

Research

The envisaged framework will see the CQT form the fundamental research wing of the innovation cycle. The Centre will remain based within the School of Physics at the University of KwaZulu-Natal. It will focus on the development of new theory and applications of quantum physics in the ICT and related sectors. This includes quantum computers, cryptography and metrology among other things. The Centre will be technology driven with blue sky research and proof of principle experiments with potential application into industry.



The proposed Quantum Innovation Framework

Development

The developmental stage of the innovation cycle is envisaged to be housed within a Centre of Competence. For ease of reference the Centre of Competence will hereon end be referred to as the Quantum Innovation Hub (QIH). The QIH will be established as an intra-disciplinary research institute allowing for the widest collaborative approach. The role of the QIH is the development of industry related quantum technology for commercial benefit. This structure would therefore be an applied research institute focussed on market driven solutions. Technology development undertaken at this institute will be at most 5 years ahead of commercial deployment. The focus of the QIH will be to:

- develop and deliver quantum-related products and services
- contribute significantly to creating and retaining a technological skills base in SA
- spin off new enterprises
- play a meaningful role in SA's socio-economic development

In a recent visit to the CQT, Minister N Pandor expressed her support for such an initiative.

Commercialization

QZN Technology (Pty) Ltd will drive the commercialization process. The company is a spin off of the University of KwaZulu-Natal and headed by the inventors from the CQT.

In terms of the innovation cycle, the company will serve as the commercial wing for products developed within the QIH. QZN is a technology driven company. Its value proposition is to:

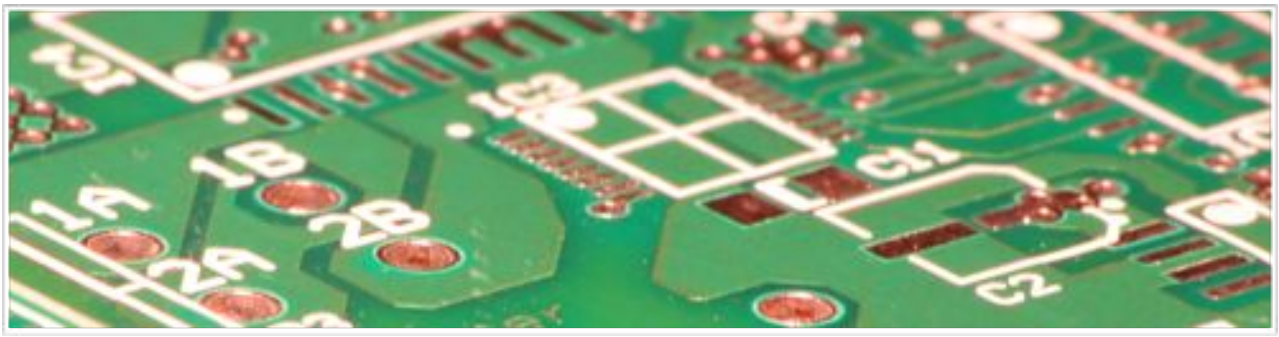
- provide high-end communication security solutions;
- provide quantum-based technologies to enhance the conventional ICT spectrum; and
- manufacture customized devices through MEMS technology for quantum-enabled products.

A portion of the accrued revenues will be reinvested into the innovation cycle, at both the research and development phases, providing for a self-funding model. In a recent visit to the CQT, the Premier of KZN and chancellor of UKZN, Dr. Z Mkhize, expressed his support for this venture.

The sustainability of this framework is governed by four key long-term objectives. These are:

- the development of an advanced knowledge base in quantum information,
- the creation of new opportunities for students to apply this knowledge,
- the development of a South African premier industry focused on quantum technologies, and
- positioning South Africa to take advantage of economic and social benefits of research.

Such objectives fit with national and provincial goals, such as: promoting innovation in a potentially leading and critical sector of the knowledge economy, thus enabling South Africa to compete on the world stage; building human resource capacity; bridging the innovation chasm, growing SMMEs; and building linkages in Africa.



QZN Technology (Pty) Ltd

The global need for a new generation of strategic technologies in ICT has prompted the establishment of QZN Technology. With the ICT sector on the verge of a nano-system revolution, the company will serve as a fusion between technology driven instrumentation and market needs. QZN is a technology company with its focus on innovative security solutions and research instrumentation using quantum physics. It was established in 2010 through the University of KwaZulu-Natal's innovation company, UKZN Innovation (Pty) Ltd, as a technology manufacturer for the products developed at the CQT, Africa's forerunner in Quantum Information Technology.

Business Strategy

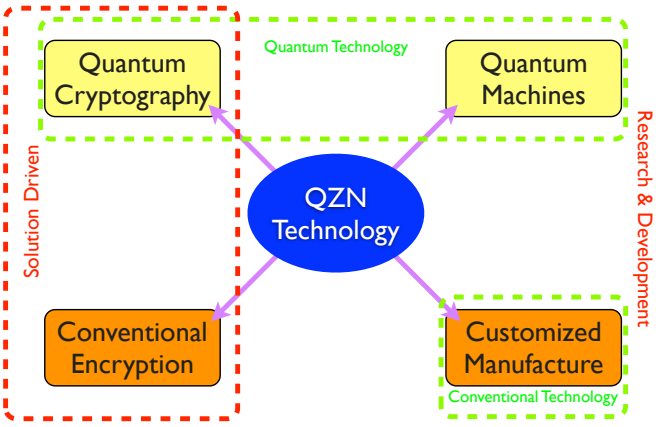
QZN Technology focuses on four core technologies grouped within three business divisions. At the heart of the company is quantum-enabled technology. Conventional solutions are, however, also offered by the firm in order to penetrate the current market and secure a market share within QIPC.



Products and Services

Conventional Encryption is imperative to preserve safety and security, as all communication mediums are prone to sniffing techniques. Conventional systems encodes the information through mathematical algorithms. Today's cryptography models suffice the needs of most small to medium enterprises and individual needs that require information security for a short to medium term.

Quantum Cryptography is the nearest-to-market application of QIPC. The objective of this technology is to secure today's data against future attempts at deciphering the information. This condition is required for classified information requiring long-term confidentiality. The enhanced security feature is due the inherent physical encapsulation of the encryption key within the physical properties of the quantum data carriers. The target market is expected to expand over the next 10 years from niche users such as governments, armed forces and research institutes to encompass commercial organizations such as finance institutes, the health sector and telecom providers.



Quantum metrology enables high precision instrumentation. Firms that embed quantum metrology techniques into their products will be ahead of competitors in appropriating the precision from the QIPC-enhancement. Depending on the application, timeframes for commercial deployment range from 3 to 20 years.

Semiconductor Devices: The long-term vision of QZN Technology is to establish a high-tech manufacturing facility within South Africa for the production of semiconductor nano-devices. The proposed facility will provide value adding technology to process semiconductor wafers. The maturing of QIPC technology for commercial usage will necessarily require a drive towards chip-based solutions. A value adding facility for semiconductor wafers dedicated to QIPC related devices is therefore a strategic investment.

Glossary

A) Alice:

This is a conventional name used to refer to the transmitter of data.

B) Bob

This is a conventional name used to refer to the reciever of data.

C) Duality

A quantum system, if unobserved, evolves as a probability distribution of wave states. Upon observation the system reduces to a singularity, characteristic to the particle nature of matter. Thus quantum systems observe both a wave and particle nature.

D) Entanglement

A quantum phenomenon in which two or more particles remain inexorably linked no matter how far apart they are.

E) Eavesdropper

One that attempts to tap into the information feed.

F) Laser Cooling

This refers to the number of techniques in which atomic and molecular samples are cooled through the interaction with one or more laser light fields.

G) Light-quanta

A name first used by Einstein in 1905 to describe particles of light, later renamed photons.

H) Photon

The quantum of light characterised by the energy E=hv and momentum p=h/λ, where v and λ are the frequency and the wavelength of the radiation.

I) Quantum

A term introduced by Max Planck in 1900 to describe the indivisible packets of energy that an oscillator could emit or absorb in his model as he tried to derive an equation that reproduced the distribution of black body radiation. A quantum of energy (E) comes in various sizes determined by E=hv, where h is Planck's constant and v is the frequency of the radiation. "Quantum" can be applied to any physical property of a microphysical system or object that is discontinuous, that can change only by discrete amounts.

J) Quantum Computer

A new paradigm of computational methods. Exploiting quantum mechanical principles to develop highly parallel processing power.

K) Quantum Cryptography

More accurately described by Quantum Key Distribution, uses quantum mechanical principles to physically encode and distribute encryption keys for safe communication.

L) Quantum Information

This is physical information that is held in the "state" of a quantum system. The most popular unit of quantum information is the qubit, a two-level quantum system. However, unlike classical digital states (which are discrete), a two-state quantum system can actually be in a superposition of the two states at any given time.

M) Quantum Mechanics

The theory of physics of the atomic and subatomic realm that replaced the ad hoc mixture of classical mechanics and quantum ideas that emerged between 1900 and 1925. Although dissimilar, Heisenberg's matrix mechanics and Schroedinger's wave mechanics are two mathematically equivalent representations of quantum mechanics.

N) Quantum Security

This is a method of securing information using the quantum mechanics as basis to the security model.

O) Qubit

The unit of quantum information that is described by a state in a two-level quantum mechanical system. The two basis states are conventionally written as |0> and |1> (Dirac notation).

P) Superposition

A quantum state composed of two or more other states. Such a state has certain probabilities for exhibiting the properties of the states out of which it is composed.

Q) Uncertainty Principle

This quantifies the inherent limitations on the accuracy of characterizing a system. The Uncertainty Principle states that measured values cannot be applied to both the position x and momentum p of a particle with unlimited precision.


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