(9.K)

Research and Technological Development

Project Proposal

within the

Framework Programme IV, 1994 - 1998

for the

Programme on Standards, Measurements, and Testing (SMT)
Theme II

ProVolt

Programmable Josephson Voltage Standards for
AC and DC Metrology

II
Part B

14	13	Lithographic masks for the final circuit generation	1; 2; 3	2.1.1; 2.2.2; 2.2.3
15	16	Test results from the a.c. and d.c. precision measurements	4; 7; 8; 10	4.1.2; 4.1.3; 4.2.2; 4.2.3; 4.2.5; 4.3.2
16	16	Improved bias systems	5; 6; 9; 11	3.2.4; 3.3.4; 3.3.5; 3.4.5;
17	16	Second progress report	all	1.1-1.4
18	24	Circuits of the final generation	1; 2; 3	2
19	24	Results of the a.c. and d.c. precision measurement	4; 7; 8; 10	4.1.4; 4.2.4; 4.3.3.; 4.3.4
20	24	Circuit diagrams of the optimum bias systems	5; 6; 9; 11	3.2.4; 3.3.4; 3.3.5; 3.4.5; 3.4.6; 3.5
21	24	Final progress report with an evaluation of the different standard types	all	1.1-1.4

Table 13: Deliverables

5. PROJECT MANAGEMENT STRUCTURE

5.1 Consortium Structure

The consortium consists of 11 partners. Each of them provides a special expertise and capabilities which are needed to contribute to meeting the objectives of the proposed project.

5.2 Management Capability of the Project Coordinator

The project coordinator is in charge for the project management and of ensuring the distribution and the quality of the deliverables. This task will be taken over by partner 1 who is a national standard laboratory with long-term experience in the development of quantum standards in worldwide international cooperation. The partner is well experienced in organising scientific projects on the national and international level. The administration of the partner is able to manage the financial organisation of international projects. Its accountancy is controlled by the usual public Audit Office.

5.3 Management Structure

The project will be started with a kick-off meeting. On this occasion, the project manager will recall the timetable of the project. The meeting will also be used to adapt the project plans to unforeseen international developments.
To coordinate the work of the individual work packages, four partners are designated as described in section 2.3. There are three work package coordinators for the scientific and technical tasks: partner 1 for the circuit fabrication, partner 5 for the development of the electronics, and partner 7 for the performance of the precision measurements. Each coordinating partner will organise the correct timing of the tasks of the work package he is in charge of. This has to be done in close contact with the other work package leaders one of whom is the project coordinator.
The project management is defined as a specific work package. It allows the implementation of the project management in the work programme and includes the current matching of the work packages, evaluation of results, planning of meetings and preparation of the reports. The project manager can be asked at any time for support and advice in case of difficulties in achieving the planned results.

5.4 Monitoring progress

To evaluate the progress of the project, two progress meetings are planned. At these meetings, the partners will report on the results of their tasks. The results will be summarised in two progress reports and a final report and submitted to the Commission. After the end of each project year, the project coordinator will submit the commission a cost breakdown of the budget of the project. The meetings will further be used to review the project progress and to adapt the project plans to unexpected difficulties or the international development, if needed. Between the meetings the project coordinator will ask for two short internal progress reports.

6. BENEFITS/ECONOMIC AND SOCIAL IMPACTS

6.1 Scientific/Technical Point of View

The Josephson primary voltage standard represents one of the most successful devices operating on the basis of the controlled transfer of single flux quanta. The proposed project is a first step towards developping superconducting circuits with a high degree of integration and smaller linewidths. This is an important step to high-performance superconducting electronics. Moreover, the project is intended to develop and connect modern room temperature electronics to superconducting devices which on the one hand will improve the handling of the quantum circuits. On the other hand, this will also provide an impact on the development of fast traditional electronics. In the future this type of ultrafast electronics may be one alternative to today's semiconductor circuits used for high speed computing. In the USA and even more in Japan this development is strongly supported.

6.2 Impact on the Industrial Competitive Position

At present superconducting circuits, the Josephson voltage standard included, are commercialised only in the USA. The project is intended to prepare the marketing of a final quantum voltmeter for fundamental a.c. and d.c. metrology in Europe. Therefore an industrial partner is taking part even in this preparatory project phase to make sure that the project results are in compliance with the needs of industry.

An easy-to-handle quantum voltmeter would improve the quality of industrial production processes and the quality of measurements in research by having a tool at ones disposal, which allows to measure relatively large voltages with extreme precision and resolution. In production processes, this is necessary more often than sensitve nullmeters. Mounted to the small and inexpensive cryocoolers which are under development at present, quantum voltmeters will replace high performance digital voltmeters because no expensive recalibration of secondary standards is needed. The drive frequency can be controlled by means of the time signal radiotransmitted by the central calibration laboratories or the signals of the global positioning system (GPS).

6.3 Impact on the Homogenisation of European Metrology

Standards on the basis of quantum effects are the ideal instruments for precise standardisation. Instead of using an artifact, they operate on the basis of a fundamental quantum phenomena which is universally valid. The proposed project intends to provide a large number of European standard laboratories with first prototypes of new Josephson voltage standards which will extend its d.c. accuracy to a.c. voltage metrology. This will allow to precisely calibrate e. g. a.c.-d.c. thermoconverters, a.c. voltmeters and wattmeters. Moreover, d.c. voltage metrology will be strongly improved by offering electronic bias sytems which would enable laboratories with no expertise in operating Josephson voltage standards to use these instruments without special staff. This will increase the uniformaty in Europe.

By broadening the basis for the fabrication of integrated superconducting circuits and making these circuits accessible to a large number of standard laboratories, the proposed project will strengthen the position of metrology in Europe. Up to now it is very difficult to operate Josephson voltage standards in calibration laboratories which do not dispose of the special expertise needed. As the proposed new programmable standards are much simpler to handle the calibration laboratories of the smaller countries will finally benefit at most from the developments of the proposed project.

To improve the accuracy of the Watt balance, very stable 1V Josephson reference voltages with a large current width of the constant voltage steps are needed. A suucessful experiment, for instance with SNS arrays, may have a strong impact on the redefinition of the SI units by replacing the „Kilogram" with the help of the electrical units. Thus the SI would be completely based on quantum recipes.

1. Physikalisch-Technische Bundesanstalt, PTB

Partner Profile
The PTB is the German standard laboratory. Strong world-wide collaboration with other laboratories has been established to develop new concepts for electrical quantum standards and to compare these. In this framework, PTB has significantly contributed to the development and present status of the Josephson voltage standard, the quantum Hall resistance standard and the investigation of single electron tunneling devices. PTB has more than 25 years of experience in the fabrication of integrated superconducting circuits like voltage standards and rapid single flux quantum logic circuits. The present research work is concentrated on decreasing the linewidth of these circuits to less than 200 nm. This work is also a subject of a European cooperation (SETAMP)

Facilities
Measurement facilities: Low-temperature equipment for measurements at temperatures between room temperature and 30 mK; microwave instrumentation up to 100 GHz; voltage standards with d.c. output voltages up to 12V.

Fabrication facilities: 400 m^2 clean room class 100; thin film equipment for fabrication of Nb-Al_2O_3-Nb and Nb-PdAu-Nb circuits and films of Pd, Cr Hf, SiO_2, SiO and MgO, reactive ion etching and ion beam etching equipment; electron beam mask writer; optical and e-beam lithography; pattern generator; CAD systems for circuit design; SEM with EDX and STM.

Key Personnel
Jürgen Niemeyer studied at the Technical University of Braunschweig (Germany) where he received his diploma degree in 1970. In 1971, he entered the PTB and started the developing arrays for the voltage standard. In the framework of his work on the influence of magnetic and nonmagnetic impurities in the barrier of SNS Josephson junctions, he received a PhD from the University of Göttingen in 1979. He worked at NIST (USA) in 1983/84 and at ETL (Japan) in 1986 and 1988 on the further development of the Josephson series array for voltage standards. In 199,1 he started the PTB research on single electron tunneling devices for future quantum current standards. At present, he heads the Quantum Metrology Section and the Clean Room Center of PTB.
Dr. F. Müller received his diploma degree in 1971 and his PhD degree in 1976 both from the Friedrich-Schiller University in Jena. His work was focused upon low temperature solid state physics. In 1991 he joined the quantum electronics section of the Phys.-Techn. Bundesanstalt in Braunschweig. He is engaged in the design and fabrication of 1V and 10V Josephson arrays.
Dr. J. Kohlmann received his diploma degree in 1986 and his PhD degree in 1990, both from the Georg-August University in Göttingen where he was working in the field of low temperature solid state physics and tunneling effects. In 1990 he joined the quantum electronics section of PTB in Braunschweig where he has been engaged in the research and development of the Josephson potentiometer and Josephson series arrays for integrated voltage standards.
W. Meier has become a Technical Engineer in 1960. At that time he was with the Technical University of Braunschweig working in the field of hydrodynamics. In 1979 he joined the Phys.-Techn. Bundesanstalt in Braunschweig where he is currently involved in the fabrication of Josephson junction devices in different technologies.

2. Istituto Elettrotecnico Nazionale Galileo Ferraris, IEN

Partner Profile
The IEN is the Italian standards laboratory which maintains and reproduces the electrical and photometric units according to the SI definitions.
The IEN Josephson array standard uses a 1V array made at the PTB. The measurement system has a microwave source which is fully phase locked by means of a phase loop control made according to an original design. The IEN JAVS is used to measure Zener diode standards with a combined type A and B standard uncertainty of 0.012.µV.
For a few years a laboratory dedicated to thin film technology has fabricated superconducting devices for precision measurement such as microbridge bolometers and SIS Josephson junctions of the Nb/A1Ox/NB type.

Facilities

Fabrication facilities: The thin film laboratory has a 20m³ class 100 clean room equipped with an optical micrometric photolitho system, 100m² class 100000 laboratory for deposition and growth of superconducting and semiconducting (silicon) films. The laboratoy comprises system for r.f. sputtering, reactive ion etching, thermal evaporation, plasma etching and LPCVD.

Key personnel

Domenico Andreone studied at the University of Genova (Italy) where he received his degree in 1972. In 1972 he joined IEN to work on the Josephson voltage standard, and became the leading researcher in this field.

At present, he is also working on the development of superconducting devices for microwave applications.

Vicenzo Laquaniti studied at the Politecnico of Turin (Italy) where he received his degree in 1975. In 1976 he joined IEN, where he started in 1979 working on Josephson voltage standard. In 1991, he set up a thin film laboratory dedicated to the realization of s.c. thin film devices for precision measurement, and he has since then been responsible for this activity.

Sabino Maggi studied at the University of Turin (Italy) where he received the degree in 1987. From 1987 to 1989 he spent 18 months at PTB, contributing to the development of the 1V Josephson array. In 1990, he joined IEN where is currently working on the realization and study of s.c. devices for precision measurements. He has also contributed to the study of a pulse driven standard.

3. VTT

Partner Profile

VTT is the Technical Research Centre of Finland. VTT employs 2600 people and is organized in nine research institutes. Researchers of VTT Electronics and VTT Automation form the VTT team in this project. The relevant expertice of this team has been accumulated mostly in in the development of SQUIDs and photon counters.

Studies of the thin film Josephson junction technology were initiated in 1969. The first successful junctions based on the Nb/NbO_x/PbIn structure were made in the following year. Development of rf SQUIDs was initiated in 1974 in collaboration with the Low-temperature laboratory of the Helsinki University of Technology. The first rf-SQUIDs were succesfully tested in 1975. These SQUIDs were designed for physical experiments marketed in the late 70s by Instruments for Technology (IT). In 1982, the thin film process was adapted to modem silicon wafer processing and the first Josephson devices resulting from this modification were an rf SQUID and a frequency/voltage converter used in a Josephson voltage standard. This instrument became the official voltage reference in Finland, Sweden, Norway and Denmark.

In 1984, VTT started to develop d.c. SQUIDs for biomagnetic measurements. A very low noise d.c. SQUID based on the conventional Nb/NbOx/PbIn structure was fabricated in 1985. To improve the reproducibility of this structure, major revisions in the processing technology were made. New junctions based on a Nb/Al/AlOx/Nb structures turned out very successfully. A record low white noise level of 0.2 μf_0 /$Hz^{1/2}$ was achieved. These d.c. SQUIDs are used in the devices of Neuromag Ltd, a company that produces and markets 122-channel magnetoencephalographic instruments. So far, VTT has dispatched d.c.-SQUID sensors for more than ten commercial systems which are used in Japan, Germany, Finland, and U.S.A.

Innovations of the VTT team include two worldwide patents from 1993 which deal with the readout electronics with a special a noise cancellation method (the high gain and the unshunted SQUID).

The Nb/Al/AlOx/Nb junction technology has been successfully used also in a project with the European Space Agency to develop superconducting tunnel junction detectors for X-rays in 1992. The development of technology for superconducting tunnel junction arrays as photon counters in X-ray, UV- and optical regime continues under a contract between VTT and ESA.

In addition to the Josephson junctioin technology, the VTT project team has a broad expertice in other areas of precision electromagnetic measurements.

Facilities of VTT Electronics

A wide range of equipment for thin film deposition, lithography and etching. The main resources are: 3 sputtering systems, 1 e-gun evaporation system, 2 reactive ion etching chambers, 1 ICP plasma etching chamber, 1 plasma enhanced CVD chamber for silicon dioxide and silicon nitride deposition, 2 contact/proximity aligners and an automatic spin coater for photolithography and a dedicated system to deposit multilayer superconductor/insulator structures for the VTT d.c.-SQUID process, galvanic plating baths for Cu, Ni and solder metals.

- CMOS pilot line conforming to 0.8 µm design rules
- Exploratory BiCMOS process with nominally 1.2 µm design rules offering MPC runs
- Mentor Graphics design system supplemented with a number of individual PC based layout systems
- Mask shop equipped with two laser pattern generators
- Processing lab with full capabilities of 100 mm dia wafer processing down to 0.4 µm usable line width using a Canon FPA-2000 i1 optical reduction stepper.
- The unit processes are also being used to generate processing schemes for specialized devices such as micromechanical sensors and pixelised detectors among others.
- The processing facility comprises a clean room with a total area of 1100 m^2 of which 500 m^2 are in class 10.
- Analytical tools in the clean room include a scanning electron microscope, several optical microscopes, ellipsometer, step profilometer, four-point probe and optical transmission spectrometer, FTIR and a Dimension 3100 AFM system.
- Analytical tools outside the clean room include 2 scanning electron microscopes, a NEC SDH-2 Pelletron accelerator for Rutherford backscattering spectroscopy and a nearby access to a VG Ionex UHV SIMS instrument.
- Fully automated DC/AC electrical testing and characterization equipment for wafer level measurements.
- Cryogenic measurements in a 10 K cryocooler setup and in a liquid He 4 K dewar system.

Facilities of VTT Automation
Measurement facilities: Microwave instrumentation up to 90 GHz, facilities for measurements at 4,2 K, Josephson DC-voltage standard at 1 V, cryogenic current comparator, quantum-Hall setup, electrically shielded rooms, instrumentation for AC/DC electric metrology, impedance bridges, spectrum analyzers, network analyzers, signal generators, etc.
Design and simulation tools: Spice, Aplac, Opera (another 3-dimensional program for solving time-dependent electomagnetic fields is being purchaced), AutoCad (for designing photolitographic masks).

Key Personnel of VTT Electronics
Leif Grönberg received his M.S and Lic Tech degrees in electrical engineering from the Helsinki University of Technology in 1980 and 1984, respectively. In 1980 he joined the staff of VTT. Grönberg studied quantum-Hall effect and its device applications. He designed and fabricated MOS structures and made low-temperature measurements of their quantum transport phenomena. In 1984-1985, he worked as a visiting fellow with Prof. Dan Tsui at the Princeton University. After his return to VTT, Grönberg was involved, in collaboration with a research group at IBM, in low-temperature characterization of electronic transport properties in silicides. In 1986, he became associated with the superconducting device group. He was actively involved in developing the new refractory junction technology for VTT SQUIDs. Presently, he is responsible for the overall management of SQUID and superconducting coil fabrication at VTT.
Jorma Salmi received his M.S. degree in electrical engineering from the Helsinki University of Technology in 1982. Since 1981 he has been with VTT. It has been his main responsibility to develop thin-film processes for superconducting device fabrication. In 1982-1984, he was responsible for the device implementation of the Josephson voltage standard for Nordic countries. In 1984-1987, Salmi developed PbIn/Nb-based technology for d.c. SQUIDs. He was also responsible for the device work involved in the ESA technical assistance contract 7608/88/NL/SK concerning superconducting tunneling junction detectors for X-rays. In 1987-1990, he took over responsibility for introducing the new high Tc superconductors in the VTT SQUID process. At the same time, he contributed to the creation of the present Nb/AlOx/Nb technology for VTT. Presently, he is the activity manager responsible for the ESA contract on superconducting tunnel junction arrays.
Ilkka Suni received his M.S degree in electrical engineering in 1973 from the Helsinki University of Technology. In the same year he joined the staff of VTT where he worked on electronic and optical

applications of thin films. In 1978, he became responsible for developing fabrication technology for optical telecommunication fibers. In 1980, Suni took over a research fellowship in a thin film and ion beam technology group at the California Institute of Technology. During this assignment he worked on contact and diffusion barrier structures for solar cells, ion implantation, solid phase epitaxial regrowth of silicon and germanium and ion beam analyses of thin films and interfaces. In 1983, he became a senior scientist a group leader at VTT Electronics. His main interests have been in materials technologies for semiconductor metallizations, compound semiconductor technologies, superconducting device technologies, electroluminescent displays and, most recently, high-performance packaging issues including flip chip mounting, chip on board and multi chip modules.

Key personnel of VTT Automation

Aarne Oja studied at the Helsinki University of Technology (Finland) where he received his Ph.D. degree in 1988. He worked at Risø National Laboratory (Denmark) in 1989 and, during several short periods at universities in Gainesville (Florida), Ames (Iowa), and Sydney (Australia). Oja is one of the leading investigators of nuclear magnetism at nanokelvin temperatures. In 1995, he entered VTT Automation where he worked as the head of the electrical metrology group. He worked on quantum Hall resistance standards, Josephson standards, capacitance measurements and novel micromachined silicon sensors. Since September 1997, he has acted as the head of the Measurement Technology Division of VTT Automation.

Heikki Seppä received his diploma, Licenciate Tech., and Dr. Tech. degrees in the Helsinki University of Technology in 1977, 1979, and 1989, respectively. He worked on electrical metrology from 1976 to 1979. He then joined VTT where he continued working in the same area and extended his expertise to sensors in general. Since 1989 he has been a Research Professor. In 1994, he was appointed as the head of the Measurement Technology Division of VTT Automation. Since 1996 he has acted as the director of VTT Automation. He at present does research work on d.c. SQUIDs, quantised Hall effect, single-electron devices and microelectromechanical sensors.

Mikko Kiviranta studied at the Helsinki University of Technology where he received his diploma degree in 1992. He participated in magnetoencephalographic studies of human brain in the Helsinki Low Temperature Laboratory in 1988-89. Then he moved to VTT Electronics where he designed, developed and characterised d.c.-SQUIDs. In 1992 he joined Heikki Seppä at VTT Automation to continue the work on d.c.-SQUIDs. Since then he has had the main responsibility for the practical design, simulation, and testing of novel SQUIDS of VTT (high gain SQUID and unshunted SQUID). Presently he is finalizing his Ph.D. thesis on d.c and unshunted SQUIDs.

4. Justervesenet

Partner Profile

Justervesenet is the national standards laboratory of Norway and is organised as a „directorate“ under the Norwegian ministry of trade and industry (NMTI). Justervesenet realises, maintains and develops most of the measurement quantities of the SI system in Norway.

Justervesenet was founded 1832 and until 1987, the activites in the field of electrical standards and calibration were limited. The NMTI then decided to expand the acivity and in 1997, this resulted in the opening of a new laboratory with ~2200m^2 laboratory area. The laboratory has the most modern metrological facilities with aircondioned and screened rooms for the electrical standards experiments. Funding has also been provided for new equipment and personell. The new facility and equipment puts Justervesenet in a unique position in Norway for electrical precision measurements, calibration and research on electrical standards. Justervesenet takes part in the European cooperation EUROMET for comparison and development of standards. Justervesenet is the national coordinator for the SMT-programme on behalf of the Royal Norwegian Research Council.

Facilities

Josephson voltage standard for measurement of dc-voltages up to 3V, with two possible m-wave sources: 80mW at 75GHz ±1GHz and 50mW at 72.00 MHz ±0.05GHz. A 10V system will be operational by the end of 1997.

Quantum Hall resistance standard setup (QHE, operational from January 1998) with absorption pumped helium 3 system insert, operating down to 300mK and up to 16T. Samples up to 25 mm in diameter can be tested.

Automatic cryogenic current comparator (CCC, operational from January 1998) built by Oxford Instruments, based on a priciple developed by the National Physical Laboratory in the U.K..

Equipment and setup for calibration and measurement of AC-DC transfer standards, ACV standards and sources in the range 0.5-1000V_{rms}/10Hz-1MHz.

Various other measurement fascilities: spectrum analyser, FFT analyser, automatic impedance analyser, etc.

Key Personnel

Harald Slinde studied physics at the Norwegian Institute of Technology in Trondheim and received his diploma degree in 1986. From 1987 to 1989 he worked at the Center for Industrial Research in Oslo (now a part of the Sintef group) as a research scientist. From 1989 to 1993, he visited the Imperial College in London where he received a PhD in 1993. In 1994 he started working at Justervesenet, where he built up the low frequency a.c. voltage activity. Currently he is involved in the development of the ACV calibration service and the build-up of the low-frequency a.c. activity at Justervesenet. He is a qualified assessor for calibration laboratories within the d.c. low-frequency area for Norwegian Accreditation. Since July 1996, he has also been the coordinator for the electrical activities at Justervesenet.

Per Otto Hetland studied physics at the University of Oslo where he received his M.Sc. degree in December 1990. From 1992 to 1995 he worked as a PhD student at the University of Oslo in the field of high-T_c superconductivity. In August 1995, he entered Justervesenet and built up the Josephson array voltage standard activity. He is now responsible for the d.c. voltage activity and will be heavily involved in the new QHE and CCC-systems.

5. SINTEF

Partner Profile

The SINTEF Group performs contract research and development for industry and the public sector in technological areas and in the natural and social sciences. With 1929 employees and a turnover of NOK 1.4 billion, the SINTEF Group is Scandinavia's largest independent research organization. Contracts for industry and the public sector account for 90 percent of operating revenues. The SINTEF Group works closely with the Norwegian University of Science and Technology (NTNU). Experts in various disciplines collaborate on projects, sharing laboratories and equipment. As a foundation for the public benefit, our task is to help ensure that our know-how is used to support a sustainable growth. The results of SINTEF's work shall be reflected in the competitiveness of Norwegian industry and productivity of the public sector.

SINTEF Electronics and Cybernetics consists of seven departments. The Institute carries out research, development and survey work within a growing Norwegian and European market where high technology is in demand. Commissions range from short-term surveys within one department to programs of several years' duration, which require the participation of several departments and, in many cases, even several institutes. Results from these commissions has, in recent years, contributed to the start-up of several firms.

The activities at the Department of Photonics focus on optical fiber transmission, optical sensor and measurement techniques, fiber optic sensor technology, and on optical devices such as lasers and switches. In addition, the department works on LCD displays, characterization and fabrication of electronic and optical thin films and microstructures, analogue electronic circuit design, and electromagnetism for sensor applications.

The Department of Microelectronics focuses on two main activities: design of application specific integrated circuits (ASICs), and packaging/interconnection of electronics. Analog, digital, mixed mode, and RF ASIC are designed.

The **Department of Instrumentation** works on measurement technology, sensor development, and electronics development with particular focus on broadband communication technologies, network performance evaluation, and Fieldbus/ISIbus. Products such as basic instrument modules, are developed from board to box to system

Facilities

Design/simulation facilities:
SPICE, Intusoft SPICE for circuit simulation and optimisation,
EdWin, interactive software for circuit schematics, PCB Layout and Simulation.
VeriBest, interactive software for circuit schematics, PCB layout and simulation
Tools for FPGA design:
Workview Office, version 7.31, including tools for VHDL compilation simulation and synthesis.

MaxPlus2 version 8.1 for implementations using Altera circuits.
Xilinx Foundation Series M1.3.7 for implementations using Xilinx circuits.
Tools for Microcontroller design:
Complete development system for Motorola 68332 microcontroller, including EST series 300 emulator.
Development system for PIC - microcontrollers.
Measurement facilities:
Signal Generators to 6 GHz , Network Analyzers to 25 GHz (HP8702 and HP8510)
Oscilloscopes: various analog and digital to 20 GHz (HP and Tektronix), Bit Error testset to 3 Gbit/s
Microvoltmeters, Function Generators (HP and Wavetek)
LabView 4.1 for instrument control, data logging and processing, Spectrum analyzers to 22GHz
HP16500B Logic Analyzer with 32Ch. 16GSa/s State Analyzer, 2Ch. 2GSa/s scope

Key Personnel

Ragnar Fagerberg received his Diploma degree in 1987 from the Norwegian Institute of Technology, NTH, in Trondheim. He then continued studying high-Tc superconducting thin films at NTH and received his Dr.Ing. (Phd) in 1992. Before joining SINTEF in 1993, Ragnar Fagerberg worked one year with the Norwegian Industy Attachee in Stuttgart. At SINTEF he continued working on high-Tc superconducting films and electronic components until 1995. Since then he has been involved in sensor/instrumentation projects, and he is now managing SINTEFs work on liquid crystal displays.
Jan Stewart Rambech was born in 1960. He received his M. Sc. in electrical engineering from the Norwegian Institute of Technology , Trondheim, Norway in 1985, and the Dr. Ing. degree from the same institution in 1994. The subject of his Dr. Ing. thesis was the analysis, implementation and evaluation of an optical heterodyne phase-locked loop using broad linewidth semiconductor lasers. In 1986 and 1987 he worked for Telenor Research on high-bitrate IM/DD systems at 1 and 1.12 Gbit/s. Since 1988 he has been at SINTEF working at first with implementation of IM/DD systems up to 2.48 Gbit/s, later with various coherent optical systems. The last 5-7 years he has mainly worked with the design and implementation of the electronic subsystems in various fiberoptic sensor systems. In addition a number of prototypes for purely electronic measurement systems have been implemented.
Bjørn Halfen studied at Lunds University of Technology in Sweden, were he received a Master degree in 1983. From 1983 to 1990 he worked with ASIC based CPU design at Norsk Data AS. From 1990 to 1996 he worked as assistant professor within the field of electronics at Oslo College, Faculty of Engineering. Since 1996 he has been at SINTEF Electronics and Cybernetics, with focus on FPGA based designs for high performance interconnect electronics.
Jan Frode Lønnum received his M.Sc, in electrical engineering from the Norwegian Institute of Technology, Trondheim, Norway in 1982, and the Dr. Ing. degree from the same institution in 1987. He has since then been working at SINTEF. The last 5 years his work has focused on hardware realisation of high-speed/RF electronic modules and systems. The practical work has been design/layout of PCBs, FPGA design and characterisation/testing.

6. National Physical Laboratory

Partner Profile

The NPL has experience in a wide range of high-precision electrical measurements. The work for this project will be carried out in the Centre for Electrical Metrology (CEM). The centre develops and maintains the national standards for Electrical Metrology in the United Kingdom. It also carries out research in high-precision measurement techniques and in methods of relating electrical and mechanical units.

Facilities

Measurement facilities: 1Volt and 10 Volt Josephson Junction Arrays.

Fabrication Facilities: not relevant within this project.

Key Personnel

Ian Robinson joined the NPL in 1976 and has worked on the precise measurement of a.c. resistance, d.c. voltage, capacitance and a.c. voltage ratio. Since 1976 he has worked on the NPL moving coil apparatus which relates mechanical to electrical power. The present version of the apparatus is intended to monitor the stability of mass standards and investigate the possibility of a new definition of the kilogram. As part of this work, he has adapted the NPL 1Volt Josephson Junction array to provide a programmable voltage reference via a 60m cable.

7. Laboratoire Central des Industries Electriques, LCIE

Partner Profile

The BNM-LCIE group is concerned with direct determinations and maintenance of basic electrical standards and the direct determination of constants relative to electrical units. It is the French reference laboratory for this domain supported by the "Bureau National de Métrologie" (BNM).
A large part of its activities is devoted to the study and use of the Josephson effect as a voltage standard and the quantum Hall effect as a resistance standard. Specific cryogenic instrumentation (such as cryogenic current comparators) has already been developed for these references.
The BNM-LCIE took part in a number of international comparisons relative to quantum electrical standards (in particular, several direct and indirect Josephson voltage standards comparisons at the 1 V and the 10 V level have led to high-accuracy results).
In the domain of applied metrology, the BNM-LCIE is particularly in charge of establishing the national standards for AC voltage and current.

Facilities

Measurement facilities: voltage standards (1 V and 10 V) based on the Josephson effect (both digital automated and analog set-up are available), resistance standards based on the quantum Hall effect, cryogenic instrumentation (CCCs and SQUIDs, and associated electronics), dilution refrigerator.
All instrumentation necessary for a.c. impedance (calculable condenser, capacitance bridges, quadrature bridge, transfer standards.....).
Equipment for a.c. voltage measurements: multijunction (3D and planar) reference thermal converters and single junction converters, two thermal converters comparison set-ups (comparison uncertainty = some 10^{-7}).

Key Personnel

Gérard Genevès has been a research scientist with LCIE since 1982. He received the "Doctorat de 3e cycle de physique du solide" from the Université des Sciences et Techniques du Languedoc in 1981. At present, he is responsible for the "Fundamental and applied electrical metrology: low-frequency and d.c." group at BNM-LCIE.
Jean-Pierre Lo-Hive has been a research scientist at LCIE since 1989. He received the "Diplôme d'Etudes Supérieures Spécialisées en électronique" from the University of Lyon in 1987. He is engaged in the development of Josephson array voltage measurement systems.
François Piquemal has been a research scientist with LCIE since 1988. He received the "Doctorat en physique du solide" from the Université PARIS VII in 1988. After having been responsible for several years for the development of the quantum Hall effect as a resistance standard, he is now in charge of the study of the single electron tunneling effect as a current standard (metrologic triangle). In this framework he is developing cryogenic instrumentation specific to quantum electrical metrology.
André Poletaeff has ben an engineer with LCIE since 1989. He received the "Diplôme d'Ingénieur" in physics from the Conservatoire National des Arts et Métiers, Paris, in 1986. He is in charge of studies in the field of a.c./d.c. transfer.

8. Swedish National Testing and Research Institute, SP

Partner Profile

The Swedish National Testing and Research Institute (SP) is the Swedish National Measurement Institute for most of the measurement quantities of the SI system. The duties involve the realisation, maintenance and development of the Swedish national measurement standards and to ensure their international traceability. In this work, research and development and international cooperation play an important role. The activities within the laboratory for electrical metrology takes place in a number of temperature stabilised and shelled rooms including low temperature laboratories for measurements at temperaturers 1.5 K to 4.2 K. The two quantum phenomena, the Josephson effect and the quantum Hall effect, form the basis for voltage and resistance measurements in Sweden. In close co-operation with the Chalmers University of Technology and a number of National Measurement Institutes in Europe, SP takes part in a project to develop a new quantum current standard, SET Amp.

Facilities

Measurement facilities: low temperature equipment for measurements at temperatures between room temperature and 4K; microwave instrumentation up to 75 GHz; voltage standards with d. c. output voltages up to 11V; a.d.-d.c. transfer standards for the measurement of a.c. voltages from 1 mV at frequencies up to 1 MHz; high accuracy analogue to digital converters, ADCs.

Key Personnel
Håkan Nilsson studied at the Chalmers University of Technology where he received a Master degree in 1974. In 1977, he joined SP and since 1981 he has been responsible for the laboratory for electrical quantities and since, also for time, time interval and frequency. His field of research is the quantum Hall effect.
Gunnar Eklund studied at the University of Gothenburg where he received his M.Sc. degree in physics in 1985. He joined the laboratory for electrical metrology of SP in 1985 and started to work in the field of impedance measurements. Since 1987 he has also been working with the national Josephson voltage standards of SP.
Bert Junno has worked as a research scientist at SP since 1997. He received his PhD degree in applied semiconductor physics in 1996 at Lund University. Presently he is SP´s key person in the SETamp EU project on a current standard development based on single electronic effects. He is also involved in the maintenance and measurements on the Josephson voltage standards and the quantum Hall standards.
Stefan Svensson studied at the Chalmers University of Technology where he received a Master degree in 1987. In 1990, he joined SP and the laboratory for electrical metrology. Since 1994 he has been working on a PhD project in electrical power measurements under non sinusoidal conditions, studying and utilising high precision analog-to-digital conversion techniques.

9. Nederlands Meetinstituut

Partner Profile
The NMi is a privatised (but government-owned) company that develops and maintains the Netherlands' primary standards and carries out research in the field of high-precision measurement techniques. Within the Electricity and Magnetism Group of the NMi Van Swinden Laboratorium, research is carried out on high-precision electrical measurement techniques, such as the Josephson-array voltage standard, the quantum Hall resistance standard, the SET current standard (SETamp, project supported by the European Community), and on the a.c./d.c. transfer.
The NMi has experience in the coordinating and running of large projects, for example EUROMET projects and intercomparisons, European BCR and SMT projects, and large contracts with the Netherlands Department of Economic Affairs.

Facilities
Measurement facilities:
- 1 V and 10 V Josephson array voltage standards.
- Quantum Hall resistance standard.
- Dilution refrigerator.
- Precision measurement systems for low voltage.
- AC/DC transfer standards (LF MJTC, HF SJTC)
- Electronics laboratory for fabrication of special equipment
- Frequency generation and measurements up to 40 Ghz
- Time interval, risetime, period measurements with resolution down to 10 ps

Key Personnel
Feike Liefrink has been a research scientist with the NMi since 1994. He received his PhD from the University of Utrecht in 1993, where he studied the time-dependent fluctuations and single electron effects in semiconductor nanostructures. Presently, he is working on the Josephson voltage standard, the quantum Hall resistance standard, the application of single electron devices, and low-frequency impedance measurements.
Cees van Mullem has been a research scientist with the NMi since 1994. He received his PhD from the University of Twente in 1993. His research concentrated on the physical and the functional integration of micromechanical resonant silicon sensors with electronic circuitry. Presently, his main focus is on the a.c./d.c. voltage and current transfer standards, DC-LF high precision measurement techniques and RF power measurements.
Gerrit de Jong graduated in Electrical Engineering in 1965. He joined the Nmi Van Swinden laboratorium in 1971 as an electronic engineer, where he has been responsible for the Electronics Laboartory and where he has set up the National Standard of Time and Frequency, as well as different methods for time comparisons. He has gained experience with digital logic, RF-techniques

around 14 GHz, as well as fast pulses up to about 10 picoseconds. At present as research scientist he focusses on Two-Way Satellite Time and Frequency Transfer. He has invented and developed a special calibration method at the 100 ps level for the earth stations involved.

10. Swiss Federal Office of Metrology (OFMET)

Partner Profile
The quantum metrology laboratory of the electricity section of the OFMET is active in three different fields:

- Quantum Hall effect (QHE): investigation into the AC QHE are actually carried out.
- Josephson metrology: up to now mostly used to maintain the Swiss volt.
- Single electron electronics: International collaboration within the SETamp project of the European Community.

Measurements Facilities
Several cryogenic metrological equipments are available:
- ^{3}He top loading cryostat with a 14 T magnet
- Dilution fridge: with an epoxy mixing chamber and 14 T magnet
  or with a metallic mixing chamber and 2 T magnet
- Cryogenic current comparator bridge
- Josephson voltage standard
- Various other precision measurement equipment

Key personnel
Blaise Jeanneret obtained his PhD in experimental condensed matter physics from the University of Neuchâtel, Switzerland in 1989. Then he spent two years at the National Institute of Standards and Technology (Boulder) working in high-temperature superconductors. In 1993, he worked at the institute of Micro and Optoelectronics of the Swiss Federal Institute of Technology, doing research on the quantum Hall effect. In 1996, he joined the Swiss Federal Office of Metrology where he is mainly engaged in quantum metrology.
Beat Jeckelmann studied at the University of Fribourg, Switzerland, where he received his PhD degree in experimental particle physics in 1986. He continued research work as a visiting scientist at the Massachusetts Institute of Technology in the field of high energy physics. In 1989, he joined the Swiss Federal Office of Metrology (OFMET) where he is mainly engaged in work on the electrical quantum standards.

11. PREMA Präzisionselektronik GmbH

Partner Profile
The Instruments Division of PREMA, founded in 1970, is the European producer of high- accuracy and high-resolution digital multimeters and A/D converters. It is also deeply engaged in the development and construction of Josephson voltage standards. The ASICs division of PREMA produces bipolar, CMOS and CBiMOS integrated circuits.

Facilities
Instruments division: production facility for measurement instruments, calibration laboratory equipped, among other things with a Josephson voltage standard.

ASICs Division: 6 inch wafer facility, production line based on the SEMIC chamber local clean room concept, mask shop with e-beam mask writer, ASIC design.

Key personnel
Joachim Scheerer studied physics at the University of Mainz (Germany) where he received his Ph.D. degree in 1972. He worked as a Ph.D. student at the Max Planck Institut für Chemie at Mainz in the field of solid state physics. In 1970, he was co-founder of PREMA. At present he heads the Instruments Division of PREMA.

CONTRACT N° SMT4-CT98-2239 (DG 12 - BRPR)

The European Community ("**the Community**") represented by the Commission of the European Communities ("**the Commission**") represented by the Director General for DG XII Science, Research and Development or its authorised representative,

and

Bundesrepublik Deutschland, Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, Fachbereich 2.4 - Quanten Elektronik ("the Coordinator") ("**BRD.PTB.QE**") established in **the Federal Republic of Germany,**

Istituto Elettrotecnico Nazionale Galileo Ferraris, Laboratorio Film Sottili ("**IENGF.FS**") established **in Italy,**

Technical Research Centre of Finland, Automation ("**VTT.A**") established in **Finland,**

Norwegian Metrology and Accreditation Service, National Standards Laboratory ("**JV.LNN**") established in **Norway,**

Foundation for Technical and Industrial Research at the Norwegian Institute of Technology, Automatic Control, Electronics and Cybernetics ("**SINTEF.AC.EC**") established in **Norway,**

NPL Management Ltd., National Physical Laboratory ("**NPLM.NPL**") established in **the United Kingdom,**

Laboratoire Central des Industries Electriques, Departement Bureau National de Metrologie ("**LCIE.BNM**") established in **France,**

Swedish National Testing and Research Institute SP ("**SNTRI**") established in **Sweden,**

Nederlands Meetinstituut N.V., Van Swinden Laboratorium ("**NMIN.SWIN**") established in **the Netherlands,**

Eidgenossisches Amt für Meßwesen, Electricity, Acoustics and Time Section ("**EAM.EATS**") established in **Switzerland,**

PREMA Präzisionselektronik GmbH, Geschäftsbereich Messgeräte ("**PREMA.MG**") established in **the Federal Republic of Germany,**

(collectively *"the Contractors"*) represented by their authorised representatives,

HAVE AGREED to a project called "**Programmable Josephson Voltage Standards for AC and DC Metrology**" being carried out in the **Standards, Measurements and Testing** research and technological development programme (***"the Specific RTD Programme"***) according to the following provisions.

Article 1 - Scope

1.1 The *Contractors* shall carry out this contract jointly and severally towards the Commission for the work set out in Annex I (*"the Project"*).

(N.B.) Words which appear in italics are defined in Article 1 of Annexe II.

1.2 Subject to force majeure (including strikes, lockouts and other events beyond the reasonable control of the *Contractors*), the *Contractors* shall use reasonable endeavours to achieve the results intended for the *Project* and to fulfil the obligations of a defaulting *Contractor*. A *Contractor* shall not be liable to take action beyond its reasonable control or to reimburse money due from a defaulting *Contractor* unless it has contributed to the default. Measures to be taken in the event of force majeure shall be agreed between the contracting parties.

Article 2 - Duration

2.1 The *Project* shall last for **24** months from the first day of the month after the last signature of the contracting parties (***"the Commencement Date"***).

2.2 The contract shall be completed on the date of the final payment due by the Commission (***"the Completion Date"***). However, Articles 6, 17 and 24 of Annex II shall continue to apply after the *Completion Date* to the extent of any limitations specified in those Articles.

Article 3 - Allowable Costs and Financial Contribution (see Articles 18 to 20 of Annex II)

3.1 The estimated allowable costs of the *Project* are **1,879,039** ECU (one million eight hundred and seventy-nine thousand and thirty-nine European Currency Units).

3.2 The Commission shall contribute up to and including **50%** of the allowable full costs[1] and/or, as appropriate, **100%** of the additional costs[1] up to **1,093,513** ECU (one million ninety-three thousand five hundred and thirteen European Currency Units) of the *Project*.

All money paid by the Commission under this contract shall be taken into account in calculating the Commission contribution paid to the *Project* and determining whether the Commission has fulfilled the requirements of this Article.

In the event of any termination, the contribution will be determined in accordance with Articles 5.4 and 23.3 of Annex II and will not exceed up to and including **50** % of the allowable full costs and/or, as appropriate, 100% of the additionnal costs of the *Project*, as defined in Article 18 to 20 of Annex II.

The estimated apportionment between the participants in the *Project* is set out in the table following the contract signatures.

The amount of any indirect taxes, sales taxes or customs duties for any invoice or bill by a supplier exceeding ECU 2500 specific to the *Project*, and not directly recoverable by the participant, may be reimbursed in addition to the Community contribution in conformity with arrangements implementing the Protocol on the Privileges and Immunities of the European Communities enabling the Commission to recover such amount from a Member State.

3.3 Except to any extent specified in Article 9, no entity established outside the Community or an *Associated State* as defined by Article 1(5) of Annex II may receive Community finance under this contract. Such financing, however, is allowed for the supply of materials or equipment, or under the conditions of any approval for subcontracts in accordance with Article 3 of Annex II.

1 The cost basis to be used is set out in the table following the contract signatures.

Article 4 - Payments by the Commission (see Article 23 of Annex II)

The Commission shall pay its contribution for the *Project* in ECU as follows:

- an advance of **656,107** ECU (six hundred and fifty-six thousand one hundred and seven European Currency Units) within two months after the last signature of the contracting parties;

- a payment, or payments, of **328,053** ECU (three hundred and twenty-eight thousand and fifty-three European Currency Units) paid within two months after the approval of the respective progress report for the objectives specified in Annex I and of the corresponding payment request. The advance and the payments shall not cumulatively exceed **984,161** ECU (nine hundred and eighty-four thousand one hundred and sixty-one European Currency Units) of the maximum Commission contribution for the *Project;*

- the balance of its total contribution due **109,351** ECU (one hundred and nine thousand three hundred and fifty-one European Currency Units) within two months after the approval of the last report, document or other *Project Deliverables* specified in Annex I (*"Project Deliverables"*) and the corresponding payment request for the final period as specified in Article 5.2.

Article 5 - Payment requests (see Article 21 and Part D of Annex II)

5.1 Two signed payment requests shall be submitted through the Coordinator each **12** months from the *Commencement Date*.

5.2 The payment request for the final period, in the format specified in Part D, shall be submitted not later than three months after the approval of the last report, document or other *Project Deliverable*, following which no further costs shall be allowable for payments .

Article 6 - Reports (see Article 10 of Annex II)

Reports shall be submitted through the Coordinator in **3** copies in **English** as specified in Annex II.

The periodic reports are required as follows:

- progress reports each **6** months from the *Commencement Date*.

Article 7 - Ownership, Exploitation and Technology Transfer

Ownership, exploitation and the granting of licences or rights in respect of *Foreground* referred to in Article 1(18) of Annex II shall accord with Part B of Annex II.

Article 8 - Amendments

This contract including its annexes may be modified only by a written agreement by duly authorised representatives of the contracting parties.

Article 9 - Special Conditions

9.1 The *Specific RTD Programme*

There are no special conditions relating to the *specific RTD Programme*.

9.2 The *Project*

The following conditions shall apply to the Project:

(a) For the purpose of this contract, the only Associated States are Iceland, Liechtenstein, and Norway, on the basis of the Agreement on the European Economic Area, and Israel, on the basis of the Agreement on scientific and technical cooperation concluded with the European Community on 25.03.96. If and when the agreement of the type referred to in Article 1(5) of Annex II currently being negociated with the Swiss Confederation is concluded, this country will automatically be considered as an Associated State with effect from the date of entry into force of that agreement.

(b) Notwithstanding Article 18.2 of Annex II of this contract, budget transfers between partners which are substantial and/or which would affect the eligibility criteria upon which the project was initially selected shall be subject to the prior approval of the Commission.

(c) The following is added to Article 4 of the contract:

1. The Commission undertakes to pay sums due pursuant to this contract within a maximum of 60 calendar days running from the date on which the Commission approves or should have approved the report(s) and/or any other Deliverable(s) due ("the approval date') to the date on which the Commission's account is debited.

2. This payment period may be suspended by the Commission if it informs the Contractor(s) concerned, at any time within the period of 60 calendar days counting from the approval date, that the corresponding payment request(s) (is) (are) not admissible either because the amount is not due or because the necessary supporting documents have not been produced or if the Commission sees the need for further checks. The payment period shall continue to run from the date on which the properly payment request(s) (is) (are) registered.

3. Upon expiry of the time limit set in paragraph 1, and without prejudice to paragraph 2, the Contractor(s) concerned may, within two months of receiving the late payment, claim interest at the rate applied by the European Monetary Institute to its operations in ECU plus one and a half percentage points.

9.3 The special conditions in Article 9.1 and 9.2 prevail over all other provisions of this contract. If Annex I conflicts with any other provision of this contract, the latter shall prevail.

Article 10 - Applicable Law and Entry into Force

The law of **the Federal Republic of Germany** shall govern this contract which shall enter into force only after the last signature of the contracting parties.

Article 11 - Annexes

The Annexes forming an integral part of this contract are:

Annex I	-	*Project* Programme
Annex II	-	General Conditions

Done at Brussels,
in duplicate in the English language,

For the Commission,

Signature: Status: Date:

For (insert acronym of the Coordinator/Contractor), IENGF. FS

Name(s): Status: Date:

Signature(s): ISTITUTO ELETTROTECNICO NAZIONALE GALILEO FERRARIS TORINO

Il Direttore generale

(dott. P. A. Mastroeni)

Table - Estimated Breakdown of the Allowable Costs

Name	Cost Basis[1]	Cost ECU	Contribution ECU
Coordinator	AC	176,000	176,000
IENGF.FS	AC	132,000	132,000
VTT.A	FC	278,000	139,000
JV.LNN	FC	134,000	67,000
SINTEF.AC.EC	FC	340,000	170,000
NPLM.NPL	FC	225,000	112,500
LCIE.BNM	FC	150,827	75,413
SNTRI	FC	139,000	69,500
NMIN.SWIN	FC	270,612	135,300
EAM.EATS	FC	(47,164)[2]	( )[2]
PREMA.MG	FC	33,600	16,800
	TOTAL	1,879,039[3]	1,093,513

1 FC = full costs; AC = additional costs

2 Not included in total costs for Community contribution (note: the costs of a non Community entity are not included in any total unless the Commission can contribute to the costs in accordance with the specific RTD programme, e.g. Contractor/Associated Contractor from an Associated State, as defined in Article 1(5) of Annex II).

3 Excluding recurrent costs borne by Contractors/Associated Contractors using additional cost basis