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# An overview of the measurement of electrical quantities within imeko from 2003 to 2015

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ABSTRACT

This paper is a logical and complementary carrying on of the previous history dedicated to an overview of the measurement of electrical quantities, from 1979 to 2002, written by Mario Savino, an author of the present article. He started from the beginning of the IMEKO (International Measurement Confederation) Technical Committee on "Measurement of Electrical Quantities" (TC4), and then described its genesis and evolution in that period. This historical background was necessary to understand the origin of IMEKO TC4. One of the most important points was that of showing the different ways of understanding and considering the concept of both the applied measurement and the measurement science in western and eastern countries, and then, the changes concerning the TC4 activities. In the present paper, not only a short overview of the scientific and organizational progress in IMEKO TC4 from 2003 to 2015 is shown, but also some reasons and related consequences due to some global, international events. One noteworthy fact was the decision of several new countries to join the European Community, which influenced the described development and promoted new trends in measurement of electrical quantities.



**Contents**



## 1. Introduction

In the previous paper, one of the author presented the first part of history and development of measurement of electrical quantities and of IMEKO TC4, from 1979 to 2002. That paper was written with the intention and hope that "the reader will learn not only of the sequence of dates, but also of the humanity and commitment of the founding members, of the joys and difficulties that arise within a Technical Committee, and finally of the friendship among people from entire world" [1]. The history did refer to TC4 Symposia, to IMEKO Congresses, to the Workshops and the round tables organized in that period, and underlined the mission of TC4, presenting its scope, objectives, and several forms of activity.

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It is noteworthy that this presentation intends to continue the series of sequences, with their evolution in time and with the principal aim to describe the novelties in the field of electrical quantities measurement, particularly the transition from one single measurement instrument towards a process able to provide information. In this context, a historical background has a fundamental meaning, that of understanding the first shape of the TC4 and of its activities, as well as of explaining a noticeable trend towards measurement in a more and more wide range of frequencies. Starting with this assumption, the first paper examined several important topics [1]. The first topics concerned the jubilee of the strain gauge and the harmonic analysis as well as the route from power measurement to the smart instrumentation. Still under the auspices of the TC4, another point was the increase of the frequency range in measurement, what had the consequence of the advancement of HF measurement, EMC, and Electromagnetic Compatibility Testing. The standard and the expression of uncertainty were important topics of TC4 Symposia in that period. The birth of the Workshop on Analog to Digital Converter (ADC) modelling and testing had allowed for considering the trends in digital measuring instruments, wireless communication, and, finally, data acquisition systems. The appointed topics were milestones in development of measurement of electrical quantities from 1979 to 2002, and the most important events, with special reference to the historical context, had a significant role for their choice. The progress in the area of electrical measurement was and nowadays is very fast and in continuous evolution. One of the vital reasons is the exponential growth of information and of communication networks, which include the new challenges in both cognitive and applicative areas, with their measurement aspects. The computational tools, which improve the efficiency of sensors and measuring instruments, are evolving rapidly as well as the computers applied to a wide variety of engineering disciplines. The benefits of using computer technology in measurement are indisputable, and involve a more efficient utilization of resources and, as a result, a reduction of costs. On the other hand, the scope and the objectives of TC4 activity have smoothly evolved during last several years, due to the global, international changes, which influenced also the measurement science. One of the most important factors of the aforementioned evolution was the adhesion to the European Union of several new members in the years 2004–2013: Czech Republic, Lithuania, Latvia, Estonia, Poland, Slovakia, Slovenia, Bulgaria, Romania, and Croatia. At the same time, these countries had used the European research space and the numerous projects within the international cooperation, like the Fifth, the Sixth and the Seventh European Framework Programmes or the last Horizon 2020, as a chance. The priorities of the scientific areas of these projects cover such "hot topics" as Information and Communication Technologies, Energy, Environment, Transport and also Food, Agriculture and Fisheries or Biotechnology. The most important projects, dedicated and implemented in the numerous areas, had their key points concerning the highest human values for the world society, particularly safety, quality and environmental friendliness.

Quite in this context, a new meaning of measurement is present, with reference to measurement of electrical quantities and their applications. In particular, on the top of traditional topics of electrical measurements, now often modified and extended, several new issues appear, such as power and frequency measurements, modern methods of digital signal processing, metrology of analogue-to-digital and digital-to-analogue converters together with their applications in computer-based instrumentation, data acquisition system (including large-scale systems) and their applications in measurement-and-control technologies. Therefore, the TC4 field of activities, although still focused on electrical and electronic instrumentation, has assumed its inter- and transdisciplinary dimension. Taking into account this new enlarged format and extended meaning of traditionally understood electrical quantity measurement, this paper presents, discusses and comments an overview of some contemporary issues and challenges on the measurement of electrical quantities within IMEKO TC4 from 2003 to 2015.

## 2. Power quality measurement and assessment

Governments around the world have encouraged the development of alternative energy sources. All the forecasts assume that the demand for electricity will expand in the coming years. Nowadays, due to this evidence, national electricity supply systems, based on a structure with large central power stations, are undergoing a gradual transition to a decentralized structure of small and medium size generators. In support of these changes, new infrastructures and services are desirable to monitor, control and report on the assets and the Power Quality (PQ) of these private producers of energy. The energy PQ on the one hand offers to national energy operators grid stability and security as well as facilitates better grid utilization and, on the other hand, allows small producers to act promptly in case of failure by identifying the causes of the problems. The control and supervisory tasks of private producers of energy, distributed over wide areas, require the use of sophisticated schemes that must be able to ensure access and exchange of great amounts of data, which can be stored in a historical Data Base (DB) and readily used for successive processing and analysis procedures. The advent of computer networks and web-based information technology offers opportunities to quickly upgrade manufacturing systems and implement advanced methods for the diagnosis or for parametric identification.

For this reason, during the XVII IMEKO World Congress on "Metrology in the 3th Millennium" held in Dubrovnik, CROATIA, on June 22–27, 2003, organized by Mladen Borsic, one of the hot topics, among the research priorities, was the measurement and assessment of PQ, considering also the implications of the energy saving. This interest concerns not only the sources generating energy, but also the safety and effectiveness of energy transfer and utilization. Indeed, a crucial role in this area is that of measurement and assessment of PQ. Alessandro Ferrero discussed very well this subject in his invited paper [2]. Many of the papers were dedicated to the aforementioned theme. Among others, one of the opening papers regarded fundamentals of electrical power quality assessment [3], presented in a special session. During this lecture, participants were present at two classical blackouts; unfortunately, there were two electrical energy failures. A majority of the session participants were convinced that it was a trick of the session chairpersons, for underlining the importance of power quality. Really, the overload of the power network caused the faults, because of the use of numerous air conditioning devices at the same time. It was a hot summer indeed.

For the first time, in the long IMEKO history, the whole Congress in Croatia used Internet for its organization. From the perspective of that time, it was not easy to take such a decision, breaking the tradition as well as implementing a new technology. The Organizing Committee was of the opinion that the IMEKO Community must enter the new millennium using the benefits of the globalization through the World Wide Web. From the present perspective, it was an opening of the new era and a milestone in the organizational development of the IMEKO events. The TC4 contribution to the Congress was really significant and documented by 64 papers presented in 12 oral sessions and 57 papers presented in three poster sessions, considering the total number of the 489 Congress papers.

Reviewing the TC4 events of 2003, it is noteworthy that Paolo Carbone, in the frame of the IMEKO TC4 Working Group (WG)

"ADC and DAC Metrology" organized the VIII IMEKO TC4 Workshop on ADC Modelling and Testing (IWADC 2003) in Perugia, ITALY, on September 8–10, 2003. It was an event also technically sponsored by IEEE and by Italian Group of Electric and Electronic Measurements (GMEE). The scientific programme included 65 papers, out of the 80 abstracts submitted, 2 plenary talks and 1 round table. An award was presented to the student who authored the best paper. Seventeen different countries were represented in the workshop and three special sessions were organized (ADCs for telecommunications, ADCs for image processing, ADCs for wireless communications). Afterward, a committee evaluated the papers presented at the conference, as usual; selected authors submitted extended versions of their articles for a special section in the IMEKO journal *Measurement*.

In the same year, Linus Michaeli and Jan Saliga organized the third Summer School on "Data Acquisition System" in Kosice, SLOVAKIA, 29 June – 11 July 2003. The tradition of annual Summer schools started in 2001. Around 20 MS degree and PhD students from partners involved in the WG "ADC and DAC Metrology" spent two weeks long stay at the Technical University of Košice (Slovakia). Since 2003, the ERASMUS programme sponsored the Summer School on "Data Acquisition Systems". The programme of the school aimed to enhance skills of attending students from participating universities in the area of Data Acquisition Systems using various interfaces for instrumentation based on the Information and Communication Technologies (ICT) tools. Another objective was to make students familiar with common standards and products available on the market. The programme consisted of lectures delivered by experts involved in the TC4 WG and by working on individual projects by multinational teams of 2–3 students. Each team presented the achieved results at the closing seminar and participants obtained the certificate. A handbook collected the delivered lectures and students' projects. Since 2006, another university, involved in the TC4 WG, organized the Summer School for the period of three years. In addition, the main objective of the Summer School changed according to the present hot topic in the field of the virtual instrumentation. Because of missing support by the ERASMUS programme, the tradition of regular Summer Schools finished in 2015.

## 3. Innovative design and paradigms in instrumentation and measurements

Measurement methodologies were highly innovative in those years. Several researchers presented new discoveries, the creation of novel practices and developed efficient tests, specially referred to ADC, DAC and digital instrumentation. The exceptional growth of ICT (Information and Communication Technologies) allowed scientists to create new smart instrumentation. The issue is not only to design, but also to evaluate the characteristics, to calibrate instruments, and to choice, the right instrument for solving the problems. If instrumentation is central to all science, if measuring devices become always more and more precise and accurate, a good calibration is mandatory. There were many updated calibration procedures in laboratory and measurement practices, which allowed new standards. The procedures specify the schedule and requirements for calibration, performance verification, and maintenance of testing instruments and equipment. New attention is brought to the legal metrology especially for trade. New standards and regulations are legislated by governments to protect both producers and consumers. A uniform global measurement system as well as a standard conformity assessment are mandatory in achieving the acceptance of calibration and testing results in the entire world. For this reason, during the 13th TC4 International Symposium on "Measurements for Research and Industry Applications", calibration metrology and standards, automated tests for traditional and virtual measurement systems had a large emphasis. The venue of Symposium was Athens, GREECE, from the 29th September to the 1st October 2004, with the 9th International Workshop on ADC Modelling and Testing, organized under the chair of Eleptherios Kayafas and Vassilios Loumos. The celebration of the 20th anniversary of the TC4 foundation fell in that year. During the plenary session, Van Biesen et al. [4] presented an invited paper, concerning the non-governmental cooperation in measurement and instrumentation, and provided important information on the age of the knowledge based society, on globalization of research and on engineering education.

The main topics of the Symposium regarded the measurement of power and energy at low frequency as well as at radiofrequency, microwave and millimetre wave. Many researchers presented new measurement software devoted to environment quality, biomedicine, system identification and control. Traditional topics were those of digital signal processing, waveform analysis and measurement, as well as sensors, transducers, and advanced instrumentation. Finally, very important segment of the Athens meeting was the ADC Workshop, with 22 papers, which presented the research, analyses and novelties in ADC applications.

Janusz Mindykowski organized, on September 12–15, 2005, the 14th TC4 International Symposium on "New Technologies in Measurement and Instrumentation" together with the 10th Workshop on ADC Modelling and Testing, held in Gdynia and Jurata, POLAND. Gdynia is not only a modern city being a part of a Tri-city agglomeration, but also the headquarters of Gdynia Maritime University, which was a host of the plenary session. Taking into account the key words in the official name of the Symposium, a significant opening plenary session paper was dedicated to state of art in ADC and DAC modelling and testing, presented by Cruz Serra et al. [5]. This topic was at that time one of the leading subjects in the field of digital instrumentation. A presentation, based on the authors' experience, underlined their contribution in related projects within TC4 and Working Group on ADC and DAC activity. The working sessions of the Symposium and IWADC Workshop took place in Jurata, a resort situated on the Hel Peninsula on the Gulf of Gdansk on the Baltic Sea. One of the most fascinating events during the Symposium, in the opinion of all participants, was a sea voyage on board of the seagoing tall ship "Dar Mlodziezy", under the full sail from Gdynia to Hel and back. This training vessel, belonging to the Gdynia Maritime University, is not only a winner of numerous world regattas, but also is considered as one of the most beautiful sailing ships in the world. For the majority of participants, it was an unforgettable adventure in the sea, together with an on board reception. Nevertheless, there was a wide scientific programme and its general line and basic topics were the same, like in Athens 2005. Power Quality problems vary substantially from case to case. The effects on networks and equipment can result in damages and in increasing losses. To avoid that these effects remain undetected, it is mandatory to monitor continuously the quality of the electrical power. This consideration pressed the organizers of Symposium in Gdynia to change the previous topic: "Power Quality Measurement" in the new one: "Power Quality Assessment". That session was very participated not only in Gdynia, but also in the following years. Another variation concerned the topic Time and Frequency Measurement, changed in Optical Wavelength Metrology. In fact, the optical metrology have improved over time and several are the arrangements for setting up measuring instruments, because the ray-error magnitude is very low. In addition, optical non-contact measurement techniques showed exceptional performance in several applications as non-destructive testing, material characterization, and biomedical sensors.

Many areas explored in Athens had extension, development and analysis in Gdynia. Among the topics discussed in TC4 Symposia 2004 and 2005, some common tendencies may be noted. First, the focus of these Symposia was oriented towards new technologies of measurement and instrumentation, covering research as well as industry applications. The DSP technology, related not only to hardware development, but also to more sophisticated software applications, was a dominant trend in the development of both measurement and instrumentation. Second, the interest and participation were significant in the papers connected with multidisciplinary measurements. This allows metrologists to address the advanced instrumentation problems, to develop new solutions related especially to sensors and transducers. Summing up, a significant progress in interdisciplinary measurements concerned the concepts of distributed systems, networking and statistical analysis, supported by appropriate tools for big data. The wider DSP technology application suggested this approach. Third, numerous papers concerning Calibration, Metrology and Standards were presented, underlining measurement accuracy and uncertainty assessment, with new definitions and procedures focused on industrial applications.

Due to the aforementioned similarity of the topics and of presented papers from one side, and the *Measurement* journal auspices from the other, this journal published, in a special issue [6], the extended and updated versions of the papers from Athens and Gdynia/Jurata. During a closing session of the Symposium, devoted, among others, to the presentation of the venue of next IMEKO World Congress: Rio de Janeiro, Antonio Cruz Serra had significantly reduced the numerous misgivings and encouraged efficiently many people to participate. On the completion of the TC4 activity in 2004 and 2005 it should be noted, that the 3rd and 4th Summer School, on the same theme, "Data Acquisition Systems", were held: in Kosice, SLOVAKIA, 14–25 June 2004; and in Benevento, ITALY, 19 June – 2 July 2005, organized by Linus Michaeli and Jan Saliga, and Pasquale Daponte, respectively.

## 4. Metrology for a sustainable development

Cities are becoming too big and too crowded. About half of the world's population now resides in cities and that proportion will grow in the next years. The World Health Organization predicts that 60% of the world's population will live in cities by 2030, and 70% by 2050. The big challenge in urban sustainability is to develop comprehensive and consistently applicable policies over different areas. A broad and comprehensive understanding of the different factors will make the relationship between citizen and environment easier. The integration of the various efforts in material and resource consumption, air quality, energy efficiency, urban planning and management should be an absolute priority of the political effort to make our cities smarter, in the ongoing battle for sustainability.

Rio de Janeiro, BRAZIL was the venue of the XVIII IMEKO World Congress on "Metrology for a Sustainable Development" together with the 11th IMEKO TC4 Workshop on ADC Modelling and Testing (IWADC 2006), on September 17–22, 2006, organized by Gelson Rocha. For the first time in the IMEKO history, the Congress took place in the America Latina; it allowed the wide community of metrologists, scientists and engineers of this region to participate in this event. The general theme of the Congress was a kind of response for the challenges concerning a need of sustainable development of countries, regions and continents, and the possibility to understand and recognize the role of metrology in this context. The Congress not only gave rise to great interest from the academic and professional point of view, but also gave the opportunity of admiring the beauty of Brazil, with the famous beaches Copacabana and Ipanema in the heart of the Congress venue - Rio de Janeiro. The most important conclusion of the Congress was the consideration that sustainability is not a brake on the growth and the development of the society, but a smart way to organize the work according to proper economic and energetic standards on the road of good design. To define these standards, the metrology will play a role more and more significant. Sustainability should be a dynamic process able to allow constant expansion or contraction depending on markets and resources, with the respect to the environment and standards agreed within international politics.

During the TC4 Board meeting, the Chairman Antonio Cruz Serra informed that the TC4 representatives had the highest number of papers and the widest activity among all the IMEKO Technical Committees. During the meeting, the Honorary Chairman Mario Savino communicated the election of Antonio C. Serra as the IMEKO President for the following three years. In the next step, the Committee nominated Linus Michaeli and Janusz Mindykowski as new TC-4 Deputy Chairman and Scientific Secretary, respectively (under a proposal of Pasquale Daponte).

Another TC4 activity in 2006 was the sixth Summer School on "ADC & DAC Metrology" organized in Benevento, ITALY, 25 June – 7 July 2006 by Pasquale Daponte and Sergio Rapuano.

The venue of the 15th IMEKO TC4 International Symposium on "Novelties in Electrical Measurements and Instrumentation" together with the 12th IMEKO TC4 Workshop on ADC Modelling and Testing was Iasi, ROMANIA, 19–21 September 2007, organized by Alexandru Salceanu and Mihai Cretu. This TC4 Symposium was running simultaneously with the 1st IMEKO TC19 International Symposium on "Measurement and Instrumentation for Environmental Monitoring and the 3rd Technical Meeting on Remote Instrumentation in Next-Generation Grids". The two last events concerned the research priorities, present in numerous European projects. The environment received a particular attention, with its influence on our life, climate changes and the protection issue. Another topic was that of energy, confirming the interest in the study of savings, safety and economic efficiency. In addition, the theme concerning remote instrumentation in next-generation grids was a "signum temporis" of the future solutions, addressed to the smart grids. The general subject of this TC4 Symposium was well "built-in" in the area of sustainable and continuous development of metrology. It results directly from the objectives of the IMEKO TC4, which concern electrical measurements in the broad sense, i.e. including both LF and HF measurements, which are of vital importance in various fields of science and technology. Progress in the domain of electrical measurement science and related instrumentation is very fast. It offers continually new possibilities of accuracy and speed of measurement. The programme of Symposium and Workshop consisted of the opening ceremony and plenary lecture, 17 working sessions under the TC4 topics, five working sessions under the TC19 topics, a special GRID session, poster session and closing session. Working sessions were in parallel, usually in two streams. The Symposia and workshop programme included topics based on previous IMEKO TC4 tradition and experience as well as on current proposals submitted by the IMEKO TC 19 authorities. The variety of the submitted papers reflects well how broad the thematic area constitutes the subjects of interest in the field of electrical measurements and instrumentation. Through the title of IMEKO TC4 Symposium "Novelties in Electrical Measurements and Instrumentation" and the subject matter of the Symposium papers, several issues should be emphasized [7].

The participants dealt with new trends in the development of electrical quantities metrology, new tools of study in the measured processes, objects and signals as well as new areas for the application of metrology of electrical quantities. Taking into account the main tendencies observed during those IMEKO events, it should

be very strongly underlined that the DSP technology is all the time a dominating trend in measurement and instrumentation development. Observed progress in DSP technology covers not only the hardware development, but also more and more sophisticated software applications in metrology of electrical quantities supported by software measurements. In those years, DSP spread over many areas as Automated Test and Measurement Systems, Remote Instrumentation in Next Generation Grids, Power & Energy Measurements and Power Quality Assessment, Digital & Mixed Signal Processing and Waveform Analysis & Measurement. Development of new technologies would not be possible without ADC intensive research, which resulted in a remarkably large number of submissions to the ADC Workshop, oriented to such topics as Σ-Δ ADC for general application, ADC testing, ADC/ADC modelling and ADC standardization. The second observed tendency deals with such issues as radio frequency and microwave measurements, communication networks, wireless measurement transmission performance, EMC tests and properties and VDSL transmission problems. Summing up, this trend is mainly due to the telecommunication networks development and electromagnetic compatibility importance in many fields of interest. It is worth mentioning that the described tendency was also the theme of the plenary paper presented by prof. Christos Christopolus titled "The Role of Simulations in Support of Measurements at High-Frequencies" [8]. This third tendency concerning Calibration, Metrology and Standards, supported by the topic Traceability and International Compatibility of Measurements, is rather obvious and easy to explain in the light of measurement accuracy increase and improvement of its assessment. The fourth tendency concerning new areas for the application of electrical quantities metrology may be also pointed out. These areas cover Biomedical Measurements and Environmental Monitoring. The latter topic was exclusive of the 1st IMEKO TC19 umbrella, consisting of such aspects as measuring principles & methods, sensors & actuators, instrumentation & monitoring systems - all related to the field of environmental measurements. The E-learning and Education in Measurements and Instrumentation appear as very up-to-date topics, in some aspects linked with Virtual Measurement Systems. In a content-related discussion, a fast development of E-learning due to IT tools progress was underlined. At the same time, there was formulated the thesis that virtual technology is a very useful and complementary tool for teaching process, but cannot substitute at all a real-object research.

For completion of the TC4 activity in 2007, the 7th Summer School on "ADC & DAC Metrology" continued in Benevento, ITALY, organized by Pasquale Daponte and Sergio Rapuano.

## 5. Exploring new frontiers of instrumentation and methods for electrical and electronic measurement

In the first decade of the third millennium, it was possible exploring new frontiers in several fields relevant to electrical and electronic measurements. Many new experiments allowed a more and more precise characterization of measurement instruments. Much attention was payed to the performance evaluation of biological structures. Acquiring accurate electric signals from biological sources is a well-known difficult task. Electrodes, amplification, filtering, guarding, insulation, at low frequencies and low voltages are necessary in this field, because biological signals are easily corrupted by the 50–60 Hz mains power interference and noise, due to other electrical and electronic devices.

MEMS (Micro-Electro-Mechanical Systems), a technology of microfabrication, gave rise to devices and structure controlled by integrated microelectronics, for medicine applications, such as MEMS pressure sensors, microsystems for DNA identification, capillary electrophoresis, microscopes. In addition, many MEMS biochips allowed detection of hazardous chemical and biological agents. Other applications of MEMS were in the field of communication and driving vehicles. The MEMS technology at high frequency improved significantly the performance of communication circuits, resonators and filters, with reduction of power consumption and cost. There was a proliferation of MEMS gyroscopes and accelerometers for air bag and vehicle dynamic control, allowing the improvement of automobile safety and reliability.

Many wireless sensor networks in that period appeared on the market; some of them are able to produce energy by harvesting, a process for capturing small amounts of electrical energy utilizing heat, light, sound, vibration or movement. With different technologies, it will be possible to feed electrical devices without mains power, reducing significantly deploying and exercise costs.

Devoted to these topics and organized by Marcantonio Catelani, the venue of the 16th IMEKO TC4 International Symposium on "Exploring New Frontiers of Instrumentation and Methods for Electrical and Electronic Measurements" integrated with the 13th International Workshop on ADC modelling and testing, was Florence, ITALY, on September 21–24, 2008. With the Workshop, it took place an interesting contemporary metrological event: the IEEE TC10 Technical Meeting on "Waveform Generation Measurement and Analysis". It was a constructive and tentative initiative undertaken once again for trying the ice breaking between the IEEE and IMEKO bodies. That event consisted of five working meetings, including two sub-committee meetings, in line with DAC and ADC subjects. Because many researchers were involved in activities both of IMEKO and of the IEEE, the opinion had grown stronger that there was no need for competition between these two institutions, whereas co-operation was possible [1]. This thaw brought Mario Savino to present an invited paper in the opening joint session of IWADC 2008. The paper dealt with an Italian project PRIN 2006, coordinated by Savino: "Development of Innovative Methods for Characterizing, Modelling and Correcting the Non-Ideal Behaviour of A/D and D/A Conversion Channels, in Order to Contribute towards Harmonizing and Upgrading International Standards". This project was part of the Italian research priorities, named Information and Communication Technology, having a general importance for the related research area. The conversion of electrical signals from the analogue to the digital realm, and vice versa, is the key operation in uncountable electronic appliances and technologies. From measuring instruments to biomedical apparatuses, from radar to cellular phones, almost any modern electronic system requires that some information, in the form of electrical signal, is converted one or more times between the analogue and the digital domain. An important aim of the research was to achieve a better knowledge – from both the mathematical and the technological point of view – of the error mechanisms in A/D and D/A conversion systems. Besides, another concrete result of the project, included also for the purpose of an easy "ex-post" evaluation of the performed research work, was the submission of the research results to the IEEE and possibly to standardization bodies (IEC, ISO), aiming at their inclusion in technical Standards relevant to A/D and D/A conversion, electronic instrumentation, and measurement uncertainty. Another TC4 goal was to support the cooperation not only with the IEEE, but also with other IMEKO Committees, so it is worth mentioning the interesting initiative undertaken with Franco Pavese (Italy): the IMEKO TC4 - TC21 Joint Session, focusing on typical aspects of measurement and instrumentation for electrical quantities as well as on mathematical tools for measurements. The most interesting aspects concerned the expression of uncertainty, the description of measurement accuracy and different mathematical tools for monitoring of environmental parameters and statistical characterization of selected phenomena. TC21 is the Committee on Mathematical Tools for Measurements, officially

established in the year 2004, under the leadership of Franco Pavese. The reason of the co-operation, between these two Committees, lies in the fact that studies of the dynamics of measurement instrumentation made more and more extensive use of mathematical tools. These trends coincided with the existence of extensive databases of parameters for commercial measuring devices. Normally the first step in studying the dynamic behaviour of a measuring device is the simulation by a model. The interesting question is whether, or not, simplified models can represent most instruments. Mathematical tools are essential not only for the study of the measuring instruments' behaviour, but also in the field of measurement uncertainty. The guide to the uncertainty of measurement (GUM) employs many concepts of probability and statistics. This explains the need for a strong symbiosis between TC4 and TC21.

The choice of Florence as location for the Symposium in Italy allowed the participants at the Symposium to admire the Italian art, which always generated great interest and involvement in the world, due to the important and consistent production of monumental, cultural and artistic works. In this context, in particular, the capital of Arts is the nickname of Florence. According to the statistics produced by UNESCO, about 60% of the world's most important works of art are located in Italy, and approximately half of these are in Florence. The Italian Renaissance began in Florence with Brunelleschi. Leonardo da Vinci, who was one of the most famous Italian Renaissance artists, is an exceptional example of merger of an artist and a scientist.

The opening of Symposium and workshop programme scheduled the plenary IMEKO TC4 lecture entitled "Systematic-error modelling, with an application to complex permittivity measurement" [9] presented by Maurice G. Cox and dedicated to the fond memory of friend and colleague Professor Gaetano Iuculano. A starting point to the plenary lecture was the assumption that systematic errors often have greater influence on a measurement than random errors. In many cases, these errors vary in an unknown functional manner with an independent variable in both time and frequency. The presented approach was inherent to a set of complex permittivity data, in which the physical model was inconsistent with the data, but augmenting this model by a systematic-error model gave its consistency.

The local organizing committee devoted this edition of TC4 Symposium to Gaetano Iuculano, who strongly wanted that the meeting could take place in Firenze and unfortunately passed away in 2007. To this aim, a student received a grant for the best paper award. Many papers focused on traditional topics, like "Power" (including its "Quality Assessment"), "Energy Measurement", "Sensors and Transducers" as well as "Automated Test and Measurement Systems". Considering the title of the Symposium, the mutually penetrating relationships between electrical and electronic measurements were evident. Moreover, the considered year showed very clearly that reconsidering the list of the topics, usually taken into account in the past Symposia, was necessary. Traditional measurements of electrical and non-electrical quantities, the methods of analysis, as well as their sensors, transducers and systems, in many cases were not enough to present a full picture of the state of the art in the selected field. A significant innovation of the Symposium was to introduce interdisciplinary, multi-subject special sessions. The titles of those sessions give a very good overview of the current development trends in the domain of metrology [10] covered by the IMEKO TC4 and IWADC: "Measurement on Human Being", "Instrumentation, Measurements and Methods for Quality, Reliability, Testing and Fault Diagnosis", "EMC Measurements and Testing", "E-learning as Educational and Technological Innovation", "Measurement in Telecom". A distinctive feature of the first special session was introducing a considerably large number of weakly-defined measurands related to human activity, which appeared in many presentations e.g. in those concerning the mammographic images for breast cancer identification, level of consciousness when driving an automobile or prediction of athlete performances. At the same time, some new topics focused on the assessment of human life, behaviour and perception, like bio-impedance, trans-thoracic impedance or skin impedance. Another distinctive feature of this conference was its attention to the widely known problems of quality, reliability and diagnostics, in the light of appropriately applied methods and measuring systems, for a very wide spectrum of different scientific and industrial applications. The third special session dealt with the more and more serious problem of electromagnetic disturbances and the necessity of their compensation. As usual, the topic concerning E-learning appeared to be a very up-to-date issue. Special attention had the application of Virtual Measurement Laboratories in Engineering Education. As the result of this session, an interesting paper indicated some weaknesses of the Bologna Declaration implementation in the Czech Republic. There are three areas, where Czech technical universities indicated problems in the implementation of new bachelor curricula: regard to assertion in practice, continuing in master stage and mobility. It seems that the remarks presented above have a more general character, related not only to Czech technical universities' experiences.

The development of new technologies and their applications in the above-mentioned areas would not be possible without ADC intensive research and its achievements. That year, this segment was introduced by the IMEKO IWADC opening lecture titled "A brief history of the Analog Digital Converter" [11] presented by C. Lyded from Analog Devices, Cork, Ireland. This talk took the audience for a brief walk through the history of Analog to Digital converter, with a bias towards commercial application. The lecture illustrated how recent main architectures evolved in the context of the most important driving applications of the time and of the available manufacturing technology. The lecture also concerned the evolution of ADC performance. The mostly discussed topics during the ADC Workshop were two leading subjects: "AD & DA advanced techniques, circuits and application" and "ADC modelling and testing".

Summing up, the IMEKO TC4 Symposium in Florence, 2008, together with the related metrological events had the highest number of presented papers (193) in the history of TC4 Symposia. The reason was undoubtedly a combined character of the meeting, including a junction of parallel events dedicated to the IMEKO TC4 Symposium, the IMEKO TC21 Symposium, and the IWADC and IEEE - TC10 meetings, from one side, while, from the other side, the choice of the venue and a well conducted and balanced scientific and cultural programme contributed to that success. The date of the Symposium - 2008, was corresponding to the 50th anniversary of the IMEKO founding, as underlined and expressed in the paper "IMEKO - the Instrumentation and Measurement Confederation" [12] elaborated and presented by A. Serra and L. Van Biesen, IMEKO President and IMEKO Past President, respectively.

By closing the picture of IMEKO TC4 activity in 2008, the traditional TC4 Summer School, named the 8th Summer School on "Distributed Measurement Systems" took place for the three consecutive years in Gavle, SWEDEN. Peter Handel and Niclas Bjoersel organized it as a two-week-event at the turn of June and July 2008, 2009 and 2010, respectively.

## 6. New look at fundamental and applied metrology

In those years, micro and nanotechnologies, based on the advances of the semiconductor technologies, had a further development in all scientific and industrial societies, increasing their economic importance. Within TC4, there was a discussion about

the opportunity of the creation of a Working Group on micro and nano metrology. The proposal started from the Chinese delegation and required several TC4 meetings. Miniaturization and nano processing were revolutionizing the manufacturing of measurement instruments (MEMS – micro electro-mechanical systems, NEMS – nano electro-mechanical systems). Accurate and precise methods of measurement and well-established procedures needed especially in the field of quality assurance and control. Nanotechnologies posed very big problems for metrologists in terms of instrumentation, calibration, artefacts, and standards. Many of these problems were subject of discussion during the XIX IMEKO World congress on "Fundamental and Applied Metrology" together with the 14th IMEKO TC4 Workshop on ADC Modelling and Testing held in Lisbon, PORTUGAL, on September 6–11, 2009, and organized by Pedro Silva Girão and Pedro Ramos. By choosing the aforementioned theme of the Congress, the organizers wanted to stress the importance of both Fundamental Metrology that includes the bases of Metrology and all Metrology aspects more close to applications. More than ever, everyday life and trade rely and depend on the development of state-of-the-art technology-based metrology. The theme was clearly broad and offered the possibility of participating to all people working in Metrology, such as scientists, engineers, mathematicians, chemists, physicists, instrumentation designers, as well as developers of measuring techniques, coming from either academia or industries. The subjects of the five invited talks, belonging to a quite diversified research space, gave emphasis to Fundamental and Applied Metrology. They covered the actual and future challenges in metrology related to terahertz based imaging, the vision of the successive ten years of world metrology, metrology challenges in biofuels and in medical measurement, as well as in space metrology as a cosmic vision. Such a choice corresponded well to the general theme of the Congress and underlined the universal nature of metrology. The Congress programme, except the five previously mentioned invited papers, had scheduled 82 oral and 4 poster sessions. In addition, four workshops, proposed by the TCs Chairmen, were included in the programme. Among the workshops, one of them on "Measuring the impossible: Measurement of Characteristics Related to Human Perception and Interpretation" seemed to be the event opening a new thinking and overcoming traditional schemes. In this context it is worth mentioning a paper written by G. Battista Rossi and B. Berglund "Measurement Related to Human Perception and Interpretation - state of The Art and Challenges" [13], being an example of interdisciplinary, i.e. technical and psychological approach to the discussed matter. Finally, four round tables on the VIM, on continuous and dynamic calibration in force and torque, on traceability in chemistry, health, food and nutrition and on higher education in the 21st century, respectively, were among the other interesting events.

Taking into account a total number of 551 full Congress papers accepted for publication, a contribution of TC4, expressed by 116 published papers, was significant and described well the leading role of this TC in the IMEKO structure. One of the workshops was composed of four sessions, dedicated to analogue-to-digital converters and organized under the umbrella of TC4 by P. Daponte and L. Michaeli. To complement the technical programme and to underline the strong connection between IMEKO and industries, an interesting exhibition was also present in the halls of the Congress centre. From the TC4 perspective, 13 oral sessions covered several topics. Traditional ones were Direct Current and Low Frequency Measurement, Digital and Mixed Signal Processing, Power Quality Assessment, Power and Energy Measurement, as well as Waveform Analysis and Measurement. Several participants followed the sessions of Sensors and Transducers, Calibration, Metrology and Standards, Advanced Instrumentation, Software Measurements, Measurement for System Identification and control, Automated Test and Measurement Systems. Devoted to high frequencies were the sessions of Radio Frequency, Microwave and Millimetres Wave Measurements. But it should be added, that the contribution of the TC4 representatives and associated participants was not limited to the TC4 sessions, a quite good number of the metrologists presented their papers in other TCs sessions, like TC21 (Mathematical Tools for Measurements), TC17 (Measurement in Robotics), TC10 (Technical Diagnostics) or TC7 (Measurement Science).

Linus Michaeli and Jan Saliga organized in the next year, from September 8th through September 10th, 2010, the 17th IMEKO TC4 Symposium on "Instrumentation for the Information and Communication Technology Era", together with the 3rd IMEKO TC19 Symposium and the 15th International Workshop on ADC Modelling and Testing, in Kosice, SLOVAKIA - European City of Culture in 2013. Kosice is a city on the historical border and crossing of West and East European culture. It is very easy to observe the close relationship between the title of the Symposium and the European research priorities, relevant to Information and Communication Technologies as well as Environment. It is also easy to show many common points of the Symposia and Workshop topics with applied metrology in large variety of areas. This IMEKO TC4 Symposium covered all traditionally considered topics, with an additional new one – the Advanced Instrumentation Based on Micro and Nano Technologies – organized in 12 regular working sessions, 3 poster sessions and 3 special sessions. Special sessions themes were concentrated on Non-destructive Testing, EMC Testing and Outcomes of International Research Projects. This last segment concerned mainly EU Research Projects. The topics of the IMEKO TC19 were conducted during 3 regular sessions and concerned the issues of: Monitoring and Control Systems for Environment; Sensors and Actuators, Digital Signal Processing in Environmental Measurements; Remote Sensing; Measuring Principles and Methods for Environmental Measurements, Environmental Data Evaluation and Assessment, and finally, Education and Research in Environmental Measurements. The IWADC topics covered not only the international segment of the ADC Modelling and Testing, but also overlapped the themes of Resolution Increase & Autocorrection as well as Circuits and Applications. In numerous presentations of the working sessions, the Symposium was a step ahead towards the future. Nevertheless, for all the participants of these IMEKO Symposia, the invited talk [14]. "The history of the Technical Committee 4 of IMEKO on Measurement of Electrical Quantities" presented by Mario Savino, was indeed an important event. First, because Mario summed up many years of TC4 activity, looking at the past and recognizing new challenges, and second, from the individual perspective of the TC4 members and participants of the related IMEKO events, he gave them opportunity to refresh remembrances and past undertakings. He completed the recollection of the past, during the gala dinner, showing several photos took from beginning of TC4 to the year 1988.

Mario Savino presented the second part of the TC4 history, from 1989 to 2002, during the successive 18th IMEKO TC4 International Symposium on Measurement of Electrical Quantities, (part of Metrologia 2011, together with the VI International Congress on Electrical Metrology - IX SEMETRO), which took place in Natal, BRASIL, 27–30 September 2011, organized by Gelson Rocha. He was also author of an invited talk [15] "Energy policies and renewable energy systems monitoring". He underlined that the need for a sustainable future had produced a very dynamic development of the photovoltaic world market, and that some estimates suggested the volume of business of photovoltaic systems has grown more than thirty-five percent annually over the last years. Another interesting point of the talk regarded the national electricity supply systems. These systems in the past used a structure with large central power stations. They were undergoing a gradual transition to a

decentralized structure of small and medium size generators. So new infrastructures and services were desirable to monitor, control and report on the assets and the Power Quality (PQ) of these private producers of energy. The energy PQ on the one hand offers to national energy operators grid stability and security as well as facilitates better grid utilization and on the other hand allows small producers to act promptly in case of failure by identifying the causes of the problems. Very exciting was the invited lecture [16] on the quantized Hall Effect of Klaus von Klitzing, who received the 1985 Nobel Prize in Physics for a discovery that had an exceptional impact on measuring technology, besides numerous other Awards for his fundamental contribution to quantum physics and metrology. This discovery made it possible to define a new fundamental constant, called von Klitzing constant, which, together with the Josephson constant is the base for the precision measurement of all electrical quantities. Klaus showed the photos of Nobel ceremony, when he received the prize of Royal Swedish Academy of Sciences from the hands of His Majesty the King.

With regard to the Symposium activities, the technical committee recommended selected papers for publication not only on MEASUREMENT, following a common procedure, but also on the e-journal ACTA IMEKO, a rebirth of an old IMEKO journal. On the grounds of the TC4 Board Meeting decision, Pedro Ramos was appointed as representative of TC4, to act successively as editor of this journal with Paul Regtien.

A participation in the IMEKO TC4 Symposium in Brazil was a difficult challenge for many potential TC4 members, mainly because of the distance, climate as well as travel and accommodation expenses. For this reason, more participants preferred to be present in the 16th IMEKO TC4 International Workshop on ADC Modelling and Testing - Data Converter Design, Modelling and Testing (IWADC) organized together with IEEE ADC Forum in Orvieto, ITALY, 30 June–01 July 2011, by Paolo Carbone. The event, with 57 accepted papers and many interesting and nicely presented papers, was a success. A good cooperation of TC4 IMEKO and TC10 IEEE on common themes was the benefit of this workshop.

## 7. Metrology for green growth

Taking a closer look at recent discussed problems concerning the not-too-distant future of the world, some key words quoted in a number of talks and articles in science and technology come across. Green growth and sustainable development are usually the most frequent ones. Energy security, climate change and environmental conservation are not tasks reserved to individual nations or organizations, but require a worldwide co-operation. An effective cooperation and a global partnership in the field of metrology could help to face more efficiently these global challenges. The venue of XX IMEKO World Congress on "Metrology for Green Growth" was Busan, REPUBLIC of KOREA, in September 9–14, 2012, organized by Sam-Yong Woo with support of Dae-Im Kang, in that time President of IMEKO. Busan was the third host city of a World Congress in Asian region after Beijing (1991) and Osaka (2001). The President's Welcome Message exactly explained the choice of the Congress theme.

In the opinion of participants, the Congress had a great success, achieved thanks to two factors: organizational quality and its venue. The skills of the organizers from the Korean Institute of Metrology (KRISS) guaranteed this success and allowed an interesting technical visit to the KRISS laboratories in Seoul. The venue of the Congress in the second largest city in Korea, located on the south-eastern coast of the Korean Peninsula, gave the opportunity to admire an attractive coastline with superb beaches and scenic cliffs in the break times of the Congress. The Congress programme contained five invited lectures, 55 oral sessions, 2 poster sessions and 26 other meetings, including board meetings of technical committees. Participants in number of 649 from 44 countries attended the Congress. Summing up, thanks to numerous well addressed presentations and discussions, the IMEKO World Congress in Busan and the metrology community gave a substantial contribution to the development of science as well as to the improvement of the quality of human life with a strong emphasis on the need of a new philosophy for the green growth. The IMEKO TC4 contribution to the success of the Congress was, as usual, large, with an active participation in several oral and poster sessions. However, one new element is worth mentioning in the TC4 events. Just during the XX IMEKO World Congress, the new Working Group "Electrical Metrology in Nano- and Micro Technology" started its activity. Due to the efforts of Pasquale Daponte and Linus Michaeli, Wang Xiaofei, Director of Wuhan Digital Engineering Institute and Electronic Components Test Centre of CSIC (China Shipbuilding Industry Corporation), chaired a Round Table Session, promoted by the newly created group. The session dealt with several interesting aspects of ICT, concerning among other things, the graphene technology. Finally, an accepted scope of this WG, presented at the TC4 Board Meeting in Busan, covers several topics as the calibration methods and requirements for various ATE (Automatic Test Equipment) parameters with the preparation of the corresponding standards. Metrology needs research and development in order to ripen process technology. A purpose of the WG will be to develop portable ATE calibration equipment allowing their traceability. Education in electrical metrology requires international co-operation, the WG will prepare education programmes and will provide training opportunities for both students and researchers. This new initiative, thanks to a strong preliminary interest of Asian metrologists, and the support of another TC4 partner, was a chance to open a new chapter in the TC4 activities. However, basing on some years of experience of the IWADC, which is an unachievable example of working group within TC4, it is also a concrete hope besides a chance.

There was also an important tendency observed and noted during the last few TC4 Board Meetings - a pressure of the IMEKO participants as well as the representatives of some IMEKO MOs (member organisations) for inclusion of the IMEKO proceedings and journals in the Web of Science (Web of knowledge database system). There was also a similar interest of TC4 to support the efforts of the IMEKO community members towards the indexing in the SCOPUS database system. These inclusions were and continue to be important for the career development of young researchers, today built mainly on – unfortunately, but it is a fact – the bibliometric indexes.

The last formal act at the TC4 Board Meeting in Busan, was the traditional "Change of the guards". The TC4 Board elected Janusz Mindykowski from Poland (Chairman), Dominique Dallet from France (Deputy Chairman) and Pedro M. Ramos from Portugal (Scientific secretary) for the next three-year term of office 2012–2015.

To complete the events concerning the TC4 activity in 2012, it has to be remembered the 12th Summer School on "Distributed Data Acquisition Systems", which took place in Cosenza, ITALY, 23–28 July 2012, organized by Domenico Grimaldi. A focus of that Summer School was "Advancements in Signal Processing" and their influence on development of the related algorithms, procedures and instrumentation.

## 8. A look at new measurements of electrical quantities

The science of measurement is vital in several fields. Metrology has a large impact in each area of our daily lives. In the considered years, there was an increased coordination of metrology research in the U.S. and Europe. Many scientists joined their measurement

expertise in a series of targeted projects, which supported innovation for addressing global challenges. Health, neuroscience, food, environment, energy and security had special attention and will have a brief description in this section.

Healthcare and risk assessment require accurate measurements to identify diseases. The wide diffusion of biosensors in hospitals helps doctors to prescribe the correct doses and the treatments or fast actions in a cost effective manner. Unfortunately, health measurement suffer from poor repeatability and reproducibility, so it is very difficult to define what is physiologic or pathologic. Medical devices require periodical calibration to agreed standards. More than others, the biological measurements have to be accurate and traceable to international reference standards, because the measurement object is a human being. Only accurate measurements allow precise diagnoses.

In the field of neuroscience, it is noteworthy what the U.S. President Barack Obama in his speech on April 2, 2013, at a White House ceremony packed with scientists said: "There is this enormous mystery waiting to be unlocked". He introduced the Brain Research through Advancing Innovative Neuro Technologies (BRAIN) Initiative, programme funded with several millions of dollars. Many researchers worked, and nowadays continue to study sensor arrays, which enabled to contribute to an improved understanding of how information travels into and between brain regions.

People are more and more interested in what they eat. During the Universal Expo 2015 in Milan, in collaboration with IMEKO and other Institutes, the Italian National Council of Research (CNR) promoted an event on Food Metrology: Approaches and Tools for Measuring Food Quality. The main objective of the workshop was to underline the importance of this emerging area of scientific, industrial and social interest. The assurance of measurement traceability for food constituents and contaminants is mandatory. It requires the development of standardized procedures and suitable reference materials. The reference is the International System of Units (SI). Advanced calibrated sensors are able to ensure and guarantee the quality of our food and other consumer goods.

Measurement plays a fundamental part to determine the sources of environmental changes, necessary to make global policy decisions, which should force countries worldwide to review their policies on energy, especially for greenhouse gas reduction. In spite of the interesting results obtained by research in the field of new energy sources, the expanded demand for electricity in the coming years requires to take care seriously of the climate change in all parts of the world. Environmental measurement requires the traceability to the International System of Units and the confidence in testing with certification, standardization, accreditation and calibration.

Many energy directives set targets for renewable sources, a key feature of the world energy policy. Science needs metrology for improving the efficiency of existing power plants and for developing and managing new smart grids.

Each community in the world is improving the security measures against terrorism and other threats. People and authorities are enlarging the installation of image sensors, smart vision systems and thermal imagers in seaports and airports, while intrusion detectors, smoke, and fire alarms are installed also at home, for example. Advanced remote sensors are necessary for accurate measurement of air pollution and vegetation control for safety. The applications in the area of sensors and sensing technology are increasing in order to address the world's most important markets.

Many of the aforementioned subjects were present in the successive TC4 Symposia. The venue of the 19th IMEKO TC4 Symposium on Measurements of Electrical Quantities together with the 17th TC4 IWADC Workshop on ADC and DAC Modelling and Testing was Barcelona, SPAIN, 18–19 July 2013, organized by Joaquin del Rio and Antoni Manuel. The Symposium looked into traditional TC4 topics, oriented in the context of the so-called society of knowledge. As a novelty, the 19th IMEKO TC4 Symposium expanded the subjects covered in previous editions in order to address the issues related to marine technologies and applications, under the umbrella of International Workshop MARTECH 2013 Programme, viz. "Sensors interoperability, Wireless sensor networks, Marine Instrumentation Technology". Two papers presented some new ideas concerning the aforementioned areas, addressed to precision timing in TDMA-based Wireless Sensor Network [17] and to measuring system and power management for underwater research [18]. The Technical Program included 2 invited talks, 18 oral sessions and 3 posters sessions. Among the topics of the 17th IWADC Workshop, particular interest had the session "AD & DA advanced techniques, circuits and application: $\Sigma$-$\Delta$ ADC DC and BP and their application, Auxiliary circuits for ADC & DAC modelling & testing". Numerous participants, in number of 170, attended these events with 142 accepted papers and 43 posters.

During the TC4 Board Meeting, the traditional way of IMEKO journals' editorial supporting process continued, and, at the end, Dominique Dallet and Joaquin del Rio for MEASUREMENT and Alexander Salceanu and Spartacas Gomriz for ACTA IMEKO, respectively, had the charge of the Guest Editors. During the same TC4 Board Meeting, Pasquale Daponte presented another crucial issue, concerned the IMEKO Indexing System, as an important factor stimulating a scientific evaluation process in many countries.

For completion of the TC4 activity in 2013, the 13th Summer School on "Distributed Data Acquisition Systems" preceded the 19th TC4 Symposium, still organized by Joaquin del Rio in Vilanova la Geltru/Balcerona, 15–19 July 2013, and was an important forum for young researchers in the field of metrology.

Benevento in Italy, from 15 to 17 September 2014, was the venue of the 20th IMEKO TC4 Symposium on "Research on Electrical and Electronic Measurements for the Economic Upturn" and of the 18th IMEKO TC4 International Workshop on ADC Modelling and Testing. The historical buildings of Benevento University were the frame for the two events, organized by Pasquale Arpaia and Sergio Rapuano (TC4 Symposium) and Pasquale Daponte (IWADC), respectively. For the first time, the two aforementioned TC4 events took place immediately after the annual convention of the IMEKO governing bodies, including the General Council, the Board of Officers, the Advisory Board and the Technical Board. The most important news concerning the IMEKO activity in Benevento in 2014 are in [19], with the short and synthetic overview of those events and the presentation of the three issues: organizational update, 2014 meeting of the IMEKO governing bodies, and TC4 Symposium and Workshop. According to the well-established tradition, those events covered theoretical and practical aspects of electrical and electronic instrumentation, related measurement-and-control technologies, as well as their applications. The motto of the Symposium referred to the global economic situation, which requires innovative solutions also in the area of measurement technologies, being a significant driving force of scientific, industrial and daily-life enterprises – an important factor of sustainable development in almost any field of human activity. Mario Savino, a co-author of the paper [20], presented a new multi-utility network for energy sustainability, giving innovative solutions in the area of measurement technologies. The TC4 Board Meeting proposed this paper as a basis for the TC4 Round Table during the successive IMEKO World Congress in Prague. That year, the organizers of the Symposium introduced in the programme a new type of organization, viz. numerous special sessions – mainly application-oriented sessions dedicated to transdisciplinary research. The following exemplify-

ing titles of those sessions seem to illustrate the motivation of this innovation: Forensic Data Acquisition Analysis and Measurement, Multifunctional Photonic Sensors, Synchronization Service for Measurement and Monitoring. Some new topics, such as software-related measurement aspects, appeared also in the regular sessions, which traditionally focused on automatic measuring systems, electromagnetic compatibility, and measurements for health and environment. Two special sessions had attracted researchers working outside of metrology but using methods and instruments for measuring electrical quantities. The first of them, Theoretical and Experimental Physics Meets Metrology Engineering at The Particle Accelerators Frontiers for New Knowledge, aimed to have a mutually beneficial exchange of knowledge and experience among the experts in metrology and the physicists working on high-challenging scientific problems. Similarly, the second special subject, Advanced Measurements in Geotechnics, intended to integrate research efforts of engineers and scientist interested in experimental investigation of geotechnical problems. The last idea was not so obvious for some TC4 Board Members, who defended the purity of the TC4 themes in the light of traditions and of the generally accepted topics. Finally, the common opinion by the TC4 Community was to accept new topics like Metrology for Geotechnics for the parts connected to electrical measurements. It is important for the future development of the TC4 and its topics. Nevertheless, a problem of philosophy of TC4 development is an open question and one of the future challenges. Among the highlights of the Symposium, the two keynote plenary lectures should be mentioned, i.e.: "The Higgs boson and beyond: the physics of the Large Hadron Collider experiments at CERN" [21] by Giuseppe Iacobucci from the University of Geneva and CERN, and "Pulse metrology" by Nicholas G. Paultier from NIST. The first of them opened a new horizon for many participants of the metrology meetings. The Benevento Workshop on ADC Modelling and Testing focused mainly on new methods for non-conventional ADC architectures. A halfday session devoted to software for ADC testing, combining hands-on experience with five lectures, was an innovation of that Workshop. The TC4 events in Benevento attracted 228 attendees, including 20 Organizing committee members. The book of proceedings contained 210 papers, selected out of 243 submitted manuscripts, and 5 invited lectures, by authors coming from 38 countries.

Pasquale Daponte, professor at the University of Sannio, located in this city, took the initiative to beautify the city with numerous flags of the participating countries, hanged at every luminaire pole, and banners recalling this event.

The same 2014 was also year for the Summer School. Some differences are relevant in respect to many previous ones. First, it was 3 weeks long Summer School and organized with the different formula traditionally used in ERASMUS programme. Due to the efforts of Joaquin del Rio from Universitat Politecnica de Catalunya, a successful grant application created the possibility to organize the IP Martin Summer School on Marine Technology, Instrumentation, in Vilanova i la Geltru/Barcelona, SPAIN, on June 29 – July 18, 2014. Looking at the wide and multi-disciplinary marine technology instrumentation oriented programme, it was a good chance for graduate students from seven countries, to develop their knowledge and professional skills related to the innovative nature of the project under consideration.

## 9. Measurement in research and industry

In the formal organizational schedule of the events in Prague, a scheme from Benevento 2014 has been repeated, i.e., the 2015 convention of the IMEKO governing bodies took place in August, from 28 to 30, 2015, just before the Congress. The programme of the convention included the annual meetings of the General Council, the Advisory Board, the Technical Board and the Editorial Board of the MEASUREMENT journal. As a result of the traditional election procedures, the General Council appointed new officers for the term of office 2015–2018: President (Kenneth T.V. Grattan from United Kingdom), Vice-President in Charge of XXII World Congress in Belfast (Ron Summers from United Kingdom), Vice-President for External Relations (Yon-Kyu Park from South Korea), and President-Elect (Masatoski Ishikawa from Japan). Directly after the IMEKO governing bodies' convention, Prague, CZECH REPUBLIC, was the venue of the XXI IMEKO World Congress on "Measurement in Research and Industry" from the 30th August to the 4th September 2015, organized by Jaromir Volf with a significant contribution of Vladimir Haasz and Jan Holub. The chosen motto of the Congress had the purpose to highlight the practical and immediate applicability of scientific achievements in measurement. As known and accepted, measurement science is also quite interdisciplinary and requires wide variety of knowledge and skills. In this context, interpersonal contacts, team collaboration and social networking are essential for successful development. Those assumptions were the basis for the organizational efforts and operational schemes undertaken by organizers. They created the technical programme, which had brought the opportunity to discuss topics with colleagues from different spheres such as academia, industry, instrumentation manufacturing companies and public or private research institutions. The technical programme scheduled 5 plenary sessions and 24 technical sessions. Authors from 41 countries submitted about 413 papers. Among the aforementioned plenary sessions, the invited talk concerned the Emotion Detector [22]; the challenge was how to measure the non-measurable phenomena? A relatively significant number of Special Sessions and Round Tables, as well as a wide selection of themes, included issues such as: Mobile Learning and Teaching, Advanced Magnetic and Electric Current Measurements, Challenges for Future Energy Networks, Metrology in Food and Nutrition, New SI, and Workshop on Energy Measurement. In this context, the contribution of the TC4 was significant in enhancing the IMEKO publication activity with the programme of the last IMEKO Congress, where four oral and two poster sessions were dedicated to widely understood measurements of electrical quantities – the sessions, which comprised 53 papers out of 413 that were included in that programme. On top of that, the TC4 organized a Special Session on Advanced Magnetic and Electric Current Measurement, and the Round Table on Measurement Challenges for Future Energy Networks. The last appointed issue requires additional comment. This Round Table had arisen from the paper [20], presented in Benevento 2014, and widely discussed during the related TC4 Board meeting. This Round Table was composed of the leading paper [23], presented by Carmine Landi, being in fact an introduction to the new theme and concerning the metering advancements for future energy networks. Some detailed presentations were devoted to the metrological support to the future electrical energy networks, the emerging domains and the Urban Control Centre Architecture as well as the proposal of industrial applications coherent with the discussed scenario. A great resonance of the presented topics, documented by the wide discussion and active contribution of the audience confirmed the expectations as well as the perceived limitations of actual smart grids applications.

With regard to the TC4 Board Meeting in Prague, some aspects are relevant. First, a deep discussion concerning enlargement of the TC4 areas of activity. Some TC4 Members, represented significantly by Pedro Ramos, were of the opinion, that TC4 should be more concentrated on the traditional scope and defended its purity of fields of interest. On the contrary, the majority of the present quorum, represented among others by Janusz Mindykowski and Pasquale Arpaia, put attention to the necessity to extend the vision of the

TC4 activity and coming-out to other fields, with assumption to use the methods and instrumentation typical of electrical quantities measurement. This discussion will continue in the future, because it is a challenge and a perspective change of the TC4 future role and its operation, including the idea at the basis of Summer School organization. Second, Jan Holub as the representative of the IMEKO World Congress LOC, stated that the agreement between MEASUREMENT editors and Congress organizers did not require traditional input from the TC4 for the editorial process. In other words, session chairs proposed one paper for MEASUREMENT and/or two papers for ACTA IMEKO; Ken Grattan and Paolo Carbone, as the persons responsible for the editorial process of both previously mentioned journals received the lists. Third, during the Congress in Prague, the "change of the guards" took place: following the Janusz Mindykowski recommendation, the TC4 officers for the next three-year term of office were appointed by the IMEKO General Council, viz. Dominique Dallet from France (Chairman), Pedro Ramos from Portugal (Vice-Chairman) and Alexandru Salceanu from Romania (Scientific Secretary).

To close the TC4 activity in 2015, it should be added that the 15th Summer School on "Distributed Data Acquisition Systems" took place in Vilanova i la Geltru from the 29th June to the 3rd July and was organized by Joaquin de Rio. However, this edition of the Summer School had a limited range and a reduced scale, due to the disadvantageous changes of the rules for financing such events under the Erasmus Plus Programme. Finally, the organization of Summer School was on a voluntary basis of the lecturers by some countries (UK, POLAND, SLOVAKIA, and SPAIN). The participants were only local graduates and Ph.D. students, connected or collaborating with the Technical University of Catalonia (UPC), SPAIN.

## 10. Concluding remarks

Taking into account the analysed period from 2003 to 2015 some observations are necessary. First of them, the exponential growth of information and communication networks caused the accelerated development of existing tools and the creation of new segments and trends in measurement of electrical quantities. This development concerns the enlargement of the fields of traditional electrical metrology, like metrology of analogue-to-digital and digital-to-analogue converters together with their applications in computer based instrumentation, or large-scale data acquisition systems, together with their applications in measurement-and control technologies. Therefore, the TC4 field of activity, although still focused on electrical and electronic instrumentation, has assumed its inter- and trans-disciplinary dimension. A second relevant observation regards the necessity of stronger links between scientist engineers and industry representatives to solve the most important problems within a common vision of challenges like energy, security, climate changes and environmental protection issues, enforcing a wide collaboration under the umbrella of global partnerships in metrology. These ideas today are significantly easier to realize, due to some advantageous political changes, e.g. accession of new members to the EU and new possibilities to participate in the international research space, effectively used by the TC4 partners. A third important "signum temporis" concerns the increase of administrative and formal limitations, unknown in the past, when the scientists were interested mainly in scientific activities. Today we observe a rapid development of numerous formal procedures e.g. the activity of the IMEKO governing bodies or international rules for the assessment of scientific and research activity, based on selected bibliometric factors. These objectives and external circumstances provoked new forms of pressure, which shaped scientific works and international collaboration. For example, even the TC4, as an organizational structure, and its officers, as the representatives of the international community of people engaged in measurement of electrical quantities, had to face other challenges more than those of the 90's did. Motivated by the growing bureaucratic requirements concerning publications, it was necessary to add to the routine activities of the TC4, a more active publication policy. Due to the efforts of some leading actors in the TC4 family, there was the re-establishing of the ACTA IMEKO journal and the shaping of its new editorial processes. In addition, there were new rules and procedures relevant to the preselection of conference papers for publication in MEASUREMENT journal. At the general IMEKO forum, the officers of TC4 became an active body of the IMEKO, promoting the indexing of IMEKO conference publications in the bibliographic databases. The next remark concerned the confirmation of the Technical Committee on Measurement of Electrical Quantities (TC4) to be of exceptional importance for the IMEKO. Other than the traditional organization and contribution in TC4 Symposia and related IMEKO Congresses, some tools of the best practice continued, like the TC4 International Workshop on ADC and DAC Modelling and Testing and TC4 Summer Schools. With their success, these events were fundamentally important to attract young people to the circle of TC4 followers, proponents and participants. In addition, the TC4 members organized and contributed to the success of many interesting Round Tables and Special Sessions. Finally, a few new problems should be noted with organization and financing of such events like Summer School, because of the already mentioned change of the rules under the ERASMUS Plus Programme's scheme. Nevertheless, we are sure, that the TC4 will overcome these difficulties and will smoothly develop further, even in the difficult times.

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