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Ryszard S. Romaniuk
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Editors

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Photonics and Electronics for Astronomy And High Energy Physics Experiments in Poland

FOREWORD BY EDITORS

Editors of this SPIE volume at the model of HERA tunnel equipment in DESY Institute, Hamburg, Germany

ANNUAL WILGA SYMPOSIUM ON PHOTONICS APPLICATIONS

Since six years the Editors of this volume have been organizing, with their mother Institute of Electronic Systems (ISE in Polish and IES in English) of Warsaw University of Technology (WUT), an annual, international, young researchers and Ph.D. students, Symposium devoted to photonics, astronomy, high energy physics (HEP) experiments and web engineering (optical Internet) – http://nms.ise.pw.edu.pl/ieee/sympozja. This quite unusual mixture of topics, as for a single symposium, turned out to be a great success as it attracted literally hundreds of young scientists and gifted students interested in photonics, optoelectronics, advanced electronics and related fields. The backbone connecting these diversified fields turned out to be Optical Terabit Internet of the next generation. The immense aggregated throughput of future commercial, but today under research, optical networks allows building not only trunk optical communication lines but also very sophisticated functional network-like systems. These include: extended, distributed, multi-sensor, telemetric networks; very fast optical pipeline triggering systems with loss of unnecessary information and precise catching of rare and immensely precious data events; massive distribution systems for extremely precise clock signal; multi-gigabit, TDM/WDM inter-board and inter-chip communication channels; GOL (gigabit optical link) chips; fast, mixed - serial and parallel, hybrid - photonic and electronic information processors; advanced imagers, and many more.

Applications of optical fiber and photonics technologies are especially promising in such exotic areas (well, exotic only for an average bread eater) as astroparticle physics and high-energy physics experiments. These were the main subjects, which attracted so many young people – literally exploding possibilities of photonics for the future, but applied to solve very practical problems of today. The vast bandwidth of optical technology products (here: fibre optic communications and photonics and new tens-of-Gbps TDM) may be exchanged for the following attributes of the researched functional systems, which apply optical technologies for information transmission and processing – serial as well as parallel: system intelligence; redundancy and intelligence driven reliability; core-network versatility basing on the ability to cooperate with multitude of considerably different access networks; adaptability and scalability for new, not yet existing or even predictable future applications. Some of the general terms we know today, but do not know what they would really mean. These are, as we predict today, optical network and photonics technologies driven, parts of the future virtual worlds like: virtual, large scientific laboratories doing research on a mass scale at efficiencies and costs not previously known; very effective tele-immersion (with not excluded implant interfaces) which may turn a base of future human life in say 100 years; just to mention a few of the possible milestones of the virtual world.

There always appears a problem of software or, more precisely speaking, software-hardware interaction. More and more complex hardware systems like multi-mega-gate array networks with photonic interfaces, is useless without dedicated, powerful software. The arrays include: FPGA, DSP, power PC, memory, ultra-fast EO/OE converters and some optical processors in a single chip. Today's, yet unfulfilled dream is - to be able to program these monsters (or even a network of such monsters) in the simplest way, using a future friendly macro-object language. To carve any reasonable functionality in multi-mega-gate FPGA of today one has to use either VHDL or MathCAD or any other of the so called, quite expensive (proprietary) integrated environment offered by matrix manufacturers and other firms. In the near future, we may expect novel simple public tools enabling one to embed desired functionalities into hybrid photonic-electronic mesh. Inevitably, hardware and software will more and more turn to a unified, indistinguishable entity.

These were some of the fascinating subjects of the Xth Symposium on Photonics, HEP experiments, Optical Internet and Web Engineering, held in WILGA Village near Warsaw on 23-26 May 2002. Local academic institution responsible for the meeting was the Institute of Electronic Systems (www.ise.pw.edu.pl) of Warsaw University of Technology (www.pw.edu.pl), home work place of the Editors, in cooperation with two international, well-known professional, organizations: IEEE (www.ieee.org) and SPIE (www.spie.org) and their local bodies – IEEE Poland Section (www.ee.pw.edu.pl/ieee) and SPIE Poland Chapter – (www.spie.pl). Both of these organizations have around 1000 members in Poland. Both of them have efficient working agreements with the major EE and IT professional organization in this country – The Association of Polish Electrical Engineers (SEP). Both of them have considerable activities among young researchers and students.

All these factors: carefully chosen organizing and sponsoring Institutions, including domestic like IES, WUT, SEP and international ones like SPIE and IEEE; WILGA Village as a great place for the meeting; as well as ideally fit mixture of meeting subject; and devotion of organizers, young researchers and students from PERG.IES.WUT group, a lot of them members of SPIE and IEEE; contributed equally to the eventual success of this year's WILGA Symposium. The solid proof of this success is the contents of this volume. A considerable number of presented contributions stem from original work of the M.Sc. and Ph.D. students. A lot of these contributions are done in international research environment. In this respect, for the time being, this volume seems to be unique, challenging initiative. It is also unique in different respect, as it shows very efficient cooperation between local groups of members of different professional organizations and their local offices. The Editors hope that such an idea, of presenting young researchers, and give them the first chance to publish their first international papers, will proliferate among the establishments of SPIE and IEEE.

This volume contains around 50% of all presentations delivered during the twelve topical sessions of Xth IEEE-SPIE Symposium on Photonics Applications. The rest of the papers were published (in Polish) in ELEKTRONIKA Monthly (Nos. 10/2002 and 1/2003), a professional journal covering photonics, electronics and IT engineering (www.sigma-not.pl) owned by the Association of Polish Electrical Engineers (www.sep.org.pl) and co-sponsored by the Committee of Electronics and Telecommunications of Polish Academy of Sciences (www.pan.pl/komitety-m.htm). ELEKTRONIKA Journal was a medial patron of the Symposium in this country. The announcements and reports from this meeting were also published internationally, mainly by SPIE and IEEE press and on web pages, like IEEE/GOLD. The Symposium is a part of the IEEE/GOLD development program in Poland and IEEE/R8. The Symposium also tries to integrate students and young engineer activities under the international umbrella of SPIE and specially SPIE Poland Chapter. So far these activities resulted, among others, in a considerable increase of student members in SPIE and IEEE in Poland. The Editors hope to continue this activity to keep alive and amplify these valuable trends. That is why some extended description of our research interest is included beneath as well as WILGA Symposium history and future.

WILGA SYMPOSIUM TRADITION

WILGA 2001

WILGA 2001 Symposium participants gathered under the IEEE Poland Section 25th Anniversary Flag. Editors are standing next to the flag from right side on the photo.

WILGA 2001 Symposium was organized on 25-27 May. The leading subjects of the Symposium cycle are the newest trends in photonics, electronics and related fields. The main subject of WILGA 2000 Symposium was “Realization of Photonic and Electronic Systems on the platform of the Internet” while the main subject of WILGA 2001 was “Deep Functional Integration of Photonic, Electronic and Mechatronic Systems”. The organizers were: PERG Laboratory of IES.WUT, IEEE Poland Section, Student Branch with some active cooperation of newly established SPIE Student Group of WUT (spie.mchtr.pw.edu.pl). The latter Group contributed a number of papers on 3D subjects in photonics. The Symposium had over 100 participants from nearly all EE and Mechatronics departments from technical universities over the country, like: Opole, Rzeszów, Łódź, Szczecin, Gdańsk, Wrocław, Bydgoszcz, Białystok, Lublin, etc.

Two days were devoted to scientific program (Friday and Saturday), while Sunday was all for sports. More than 50 papers were presented. The proceedings were prepared on the CD and distributed among the participants. Some additional number of CD was available for any interested persons. All presentations were multimedial. The Symposium has a tradition to open with a special invited presentation, from outside of the technical world. Prof. Ewa Czerniawska, deputy Dean of Department of Psychology of Warsaw University had a lecture on “Contexts of memory effects”. The presentation concerned the factors influencing the efficiency of learning and information storing, and was extremely interesting for students.

The topical scope of WILGA 2001 meeting was divided to several subjects usually combined with work carried out by large research teams from the mentioned universities. Such teams attract a lot of students. A group of PERG students presented several subjects from the field of advanced optoelectronic and electronic systems for HEP. This Group cooperates closely with the Institute of Physics in Helsinki and Institute of Experimental Physics of Warsaw University on construction of several CMS subsystems. Recently this Group presented a paper on the 6th Workshop on Electronics for LHC Experiment, held in Kraków.

Other strong representation had photonic imaging of 3D objects for CAD/CAM systems. This work is carried out by a group of students associated in SPIE at Department of Mechatronics of WUT. One of the most serious problems of system construction is the software layer. Experience exchange between students of different departments like physics, electronics, IT and mechatronics resulted in, on the spot, immediate solutions to number of quite complicated research problems. A very interesting topic was represented by joint work on hardware and software for Internet based metrological stations, servers and networks. An example of this work is large, public, Internet accessible, metrological network for weather and environmental parameters developed at IES WUT in cooperation with other groups from Chemical and Environmental Engineering Faculties. A few stations associated with this network have been working since several years. Some of these stations are registered in DNS as pergx.ise.pw.edu.pl (x=1,2,3…).

Apart from regular paper presentations a few panel discussions were organized. One of them concerned very hot topic for students – “Studies and work”. The following problems were debated like: How to marry demanding study at EE department and full time job? Treatment of students by the employers, Requirements from the employers for EE diploma, Foundations of group work organization, Attributes of reliable co-workers – responsibility, decency, disposability, professionalism, etc.

WILGA 2002

Initially domestic, now international Symposia on Photonics and Web Engineering are organized since several years during the last extended weekend of May. WILGA 2002 started with informal get-together party on Wednesday 22th May and ended on Sunday 26th May in the evening. The Symposium combines various forms of activities that may be attractive for young researchers: high quality conference sessions, mutual peer-reviewing of contributions, round table topical discussions, interdisciplinary debates on the hottest research subjects, problem solving, Ph.D. workshop meetings, all intermixed with nice social events.

WILGA 2002 Symposium: Sitting are from the left: dr Jan Domin, Technical University of Rzeszów, prof. Maria Suchańska, Technical University of Kielce, prof. Marian P.Kaźmierkowski, IEEE Poland Section Chair, Warsaw Univeristy of Technology, dr Maria Chorąży, ELEKTRONIKA Journal Monthly SEP, dr Ryszard S.Romaniuk, WILGA Symposium Chair and SPIE Proc. Editor from WILGA Conference. Standing in the middle from left are: dr Ryszard Kisiel, Mr Paweł Pluciński, dr Ryszard Kossowski, dr Grzegorz Pankanin, dr Krzysztof Poźniak, Mr Maciej Kudła, Donatella Ungaro, Kukka Banzuzi, Tomasz Jeżyński with wife, Zbigniew Łuszczak and Wojciech Zabołotny.

The main aims of WILGA Symposiums are:

- Integration of domestic and international M.Sc. and Ph.D. students as well as young research fellows working in optoelectronics, photonics, optical communications and associated fields like: EE, IT, mechatronics and relevant physics fields, through organization of research workshop of the highest level.
- Organization of students and young research fellow life under the wings of large professional organizations like international - IEEE, IEEE/GOLD, SPIE, EOS, EPS, OSA and domestic – SEP, SIMP, PTF, PTTS in Poland.

PERG and ELHEP Laboratories of the Institute of Electronic Systems, Warsaw University of Technology (ISE PW), organized WILGA 2002 Symposium. Main sponsors were ISE PW and IEEE Poland Section. Research patronage was extended by: IEEE Poland Section (prof. Marian P. Kaźmierkowski); Institute of Electronic Systems (prof. Janusz A. Dobrowolski); Committee of Electronics and Telecommunication of Polish Academy of Sciences and Polish Optoelectronics Committee of Association of Polish Electrical Engineers (prof Wiesław Woliński); SPIE Poland Chapter (prof. Maksymilian Pluta); Committee of Electronics and Mechatronics of SEP and SIMP (prof. Jerzy Klamka); PERG/ELHEP IES WUT Laboratory (dr Ryszard S.Romaniuk). The Symposium is entering the IEEE/GOLD program.

Initially the subject of the Symposium was connected with the organizers. Now because of large interest in the event among domestic Ph.D. student environment, the subject is not confined strictly to the Symposium title. The leading subject changes every year and during WILGA 2002 meeting was: Photonics and optical Internet in applications for HEP. Particular presentation subjects were gathered in topical sessions like: milestones of photonics; photonics in communications, industry, astronomy, Internet; Hybrid telemetric networks; Sensors and functional components; Applications of programmable matrices and VHDL programming; Software for optical networks; Materials and technologies for photonics and VLSI electronics; Photonics in mechatronics; Digital holography and measurements of 3D objects; Photonics and electronics for CMS/LHC and BAC/ZEUS/HERA HEP experiments. During the Symposium, tutors present the invited papers, while students deliver most of the regular ones. Topical sessions are organized around tutorials.

WILGA 2002 was attended by a record number of participants, well over 150 with 10 from abroad. Nearly 120 papers were presented. The international guests were from Minsk Bielarus, Bari-Italy, CERN-Geneva, Leuven-Belgium, Damascus-Syria and Hamburg-Germany. A number of students attended with their girlfriends and spouses, which added a lot to the masculine dominated subject fields of the meeting.

There are some basic principles of WILGA Symposium organization. Apart from keeping the highest possible research level, the most fundamental principle is to keep costs down for the participant. There is no entrance fee. The costs of WILGA 2002 for the participant was around 10$ per person for accommodation and all days meals. Transportation costs from Warsaw by public bus is around 3$. The travel lasts around 1 hour and the buses are every hour from Stadion Bus Station. The organizers often provide group travel from Warsaw (Faculty of Electronics and Information Technologies WUT) to Wilga. Thus, the overall costs are below 50$ for three nights and four days.

WILGA 2002 Symposium is a kind of very advanced Ph.D. student and young researcher workshop organized in fully international environment. Official language is English, with some presentations allowed in other congress languages, like Russian and German. The presentations are doubly peer reviewed and subject to Symposium debate. They are submitted on the basis of recommendation by tutors and supervisors of young research fellows. Authors of the best presentations are invited to publish their papers.

In parallel to the young research fellow advanced workshop, the Symposium has a number of invited presentations delivered by the leaders of relevant fields. Frequently, the tutors were trying to awake a discussion around the subject of their presentations. According to the students' opinion this year the best tutors were: prof.L.Mankiewicz – astronomy, prof.M.Turała – GRID, dr Zbigniew Bielecki – IR technique.

During the period of 1998-2001 the proceedings were edited and issued in the form of abstracts volume and a CD. Now an initiative was undertaken, supported by SPIE Poland Chapter and SPIE Bellingham to issue a volume of Proceedings.

Three days were devoted to scientific program and evening social events. Each evening had different program. During the first one, dr habil. Grzegorz Wrochna from A.Soltan Institute of Nuclear Studies organized a demonstration LIVE FROM JUPITER. Using a half-meter telescope, CCD web camera, a laptop a projector, and fast image processing and presenting software, observations of the Moon and close planets like Venus and Jupiter were carried out. All four, linearly arranged moons of Jupiter, were clearly visible as well as Venus phase. The second evening was devoted to panel discussion. The subjects were: international cooperation, young research fellows' exchange and the role of international organizations in professional career. The third evening was a social meeting, sponsored by IEEE Poland Section.

The WILGA 2002 Symposium was opened by a lecture of dr Ryszard Kossowski of WUT and Cardinal Stefan Wyszyński University. The lecture, which extended abstract is included in this volume, concerned the parallels between such aspects of our life as: ethics, sports, science, creativity, work, rest and fitness.

Again, several separate topical streams may be distinguished during WILGA 2002 presentations. A group of more than 20 young researchers from Poland, Italy and Finland, associated with PERG and ELHEP Groups, presented work from advanced optoelectronic and electronic systems for HEP experiments like Zeus/Hera, CMS/LHC and Tesla. This work was done at IES WUT, Institute of Experimental Physics of Warsaw University, Helsinki Institute of Physics, Bari Institute of Physics, CERN in Geneva and DESY in Hamburg. The students realize several M.Sc and Ph.D. theses in this domain. Some of them are presented in this volume of Proceedings.

WILGA 2002 Symposium photos: (from upper left to lower right) participants listening to the lectures, Astronomical Session organized by dr habil. Grzegorz Wrochna of A.Sołtan Institute of Nuclear Problems, LIVE FROM JUPITER, social scenes from Symposium panel discussion and IEEE-SPIE Wine and Cake Reception.

WILGA 2002: Symposium lecturers (from upper left to lower right): prof. Michał Turała, H.Niewodniczański Institute of Nuclear Physics, Kraków; prof. Marian P.Kaźmierkowski, IEEE Poland Section Chair; dr Grzegorz Pankanin, Institute of Electronic Systems, Deputy Director for Research, prof. Lech Mankiewicz, Dept. Theoretical Physics, Polish Academy of Sciences

The next session, on photonics in astronomy and astrophysics, was introduced by invited paper of prof. Lech.Mankiewicz from Department of Theoretical Physics, Polish Academy of Sciences. The paper concerned physics of elementary particles originating from the deep space. Investigation of these particles allows us to return in time to the moments close to the Big Bang and is an alternative and future way to carry HEP experiments without big, and thus, extremely expensive, accelerators. Two groups of students from WUT and WU are participating in observation programmes of changing objects in the sky and in a new program called "π of the sky". The latter program concerns mass and cheap observations of the whole sky for short and accidental gamma ray bursts (GRB) with accompanied optical flashes. Large astronomical telescopes are too big and too slow to observe such short lasting and totally unpredictable events. The programs are done in cooperation with Princeton University and European Southern Observatory in Las Campanas in Chile.

Around 30% of Symposium work concerned software for specialistic solutions of Internet, Intranets and functional (telemetric) access networks. These systems have more and more interactivity, relay on web driven databases. Several papers concerned distant learning program of WUT –www.pw.edu.pl/okno.

A group of topics embraced directly photonics, like: optical fibre technology, applications of multimode optical fibres in cheap transmission systems for short distances – like gigabit Ethernet, multigigabit standardized optical links to transmit compressed measurement data, optoelectronic sensors, machine vision systems of 3D objects. A number of submissions concerned practical applications of photonics in industry and environment protection.

WILGA 2003

The XIIth Symposium on Photonics and Web Engineering will take place in WILGA Village near Warsaw, a resort center owned by Warsaw University of Technology, on 22-25 May 2003. The Symposium takes place two times a year, since six years, alternatively in Wilga in May and in the Faculty of Electronics and Information Technology of WUT in January. The WILGA Symposium will gather around 200 specialists next year. The participants come from academia and research institutes – domestic and international.
The WILGA 2003 Symposium is organized by:

- IEEE Poland Section – Student Branch
- SPIE Poland Chapter,
- PERG and ELHEP Laboratories of Institute of Electronic Systems, WUT,

The WILGA 2003 Symposium is organized under the auspices of:

- IEEE Poland Section and SPIE Poland Chapter,
- Institute of Electronic Systems, Warsaw University of Technology,
- Committee of Electronics and Telecommunications, Polish Academy of Sciences,
- Polish Optoelectronics Committee, Association of Polish Electrical Engineers,
- Inter-Association Committee of Informatics, Electronics and Telecommunications, SEP-SIMP.

The WILGA 2003 Symposium Patronage Committee consists of persons leading the above-mentioned institutions.

The Symposium possesses each year a slightly different scope. The major topical emphasis in 2003 is work development on the biggest planned free electron laser (FEL). The broad area of the Symposium are advanced photonic and electronic systems in hardware and software aspects.

The WILGA 2003 Symposium will have the following topical Sessions:

- Optical Fiber Technology - multi-gigabit transmission systems and distributed multi-sensor hybrid telemetric networks; basics of optical networks; Optical Internet;
- Optoelectronics – materials, technologies and components; Lighting technology;
- Digital holography; Measurements and recognition of 3D objects;
- Advanced measurement systems for biomedicine and environment protection;
- Measurement and functional systems for high energy physics experiments and astronomy;
- Software and new functionalities of optical networks and the Internet;
- Global calculation networks – GRID;
- Organization of other topical sessions is not excluded, and depends on input from their organizers as well as on number and quality of submitted papers.

The Organizers of topical sessions are renowned domestic and international experts in relevant branches of science and technology. Particular topical sessions are filled with papers invited by Session Organizers and by presentations submitted by young researchers, M.Sc. and Ph.D. students. Supervisors or tutors of young researchers should recommend the submitted papers.

The main aim of the WILGA 2003 Symposium is to build a nation wide debating forum for young researchers and Ph.D. students with strong participation of experts and young research fellows from abroad. Membership of young scientists in IEEE (students and GOLD members) and SPIE will be emphasized during a special Society Evening and IEEE B-B-Q Reception.

The Symposium publications are subject to a standardized peer reviewing process, as in archival journals, and are printed in renowned series Proceedings of SPIE (www.spie.org and www.spie.pl) in English language. Some papers are also published in Elektronika Monthly, a journal of Association of Polish Electrical Engineers. Elektronika is a medial patron of the Symposium. The official language of the Symposium is English. The presentations are allowed also in Polish, Russian and German.

The Symposium Internet information site is: http://nms.ise.pw.edu.pl/ieee/sympozja

The WILGA 2003 Symposium Organizers invite experts in relevant subject, embracing the widely understood Symposium scope, to declare organization of topical sessions.

The WILGA 2003 Symposium Organizers invite warmly students (Eng., M.Sc., Ph.D.), young researchers from academia, research institutions, innovative spin-offs and industry to submit papers and participate in WILGA meeting. WILGA is an unforgettable and irreplaceable experience for young people.

The WILGA 2003 Symposium Organizers invite high technology firms, spin-offs and all interested businesses to meet with around 200 young researchers, the best ones in the area of photonics applications, advanced electronics, optical communications, HEP experiments and optical Internet engineering.

All information about the Symposium, organization problems, session proposal, paper submission, participation questions are available only through electronic way under the address:
photonics@ise.pw.edu.pl; R.Romaniuk@spie.pl, R.Romaniuk@ieee.org;

The Symposium participation costs are just minimal. There is no fee. The only costs are accommodation in WILGA WUT Resort Centre. These costs are estimated for 2003 to be 55 Polish Złoty per day, for night and three meals a day. That is around 14$. The participants book the rooms in WILGA of their own, under the telephone number 0-prefix-25-685-30-17 (45,47). The information about the WILGA WUT Resort Centre is available on the web: http://www.info1.pl/Noclegi/osrodki/mazowieckie/wilga/start.htm

HEP EXPERIMENTS AT DESY AND CERN

The Editors cooperate, for more than a quarter of century, with many national and international institutions active in photonics applications in such fields as: optical fibre technology and communications, environment monitoring, large industrial telemetric systems, and recently – high energy physics experiments and astroparticle physics. The Editors participated (and still are) in research on and building of several electronic systems for HEP detectors of some major accelerators like VETO WALL and ZEUS (www-zeus.desy.de), backing calorimeter (BAC) of ZEUS (hep.fuw.edu.pl/zeus), (hegemon.ise.pw.du.pl) at HERA in DESY (www.desy.de) and CMS (cmsinfo.cern.ch) (hep.fuw.edu.pl/cms) at LHC in CERN (www.cern.ch). Recently we also got involved in the low-level radio frequency control (LLRFC) for TESLA linac design at DESY (tesla.desy.de). These phases of work were known as Tesla test facility I and II (TTF). To facilitate these works, our Institute intends, with international support, to build dedicated laboratories PERG – Photonics and Web Engineering Research Group and ELHEP – Electronics for HEP Experiments Research Group. Now, these groups gather several tens of senior researchers and M.Sc as well as Ph.D. students from a few different institutions like: Warsaw University of Technology (www.pw.edu.pl), Institute of Experimental Physics of Warsaw University (www.fuw.edu.pl) and A.Sołtan Institute of Nuclear Studies (www.ipj.org.pl). Officially this cooperation bases on two agreements between DESY/TESLA and IEF WU and WUT.

The PERG and ELHEP Laboratories specialize in:

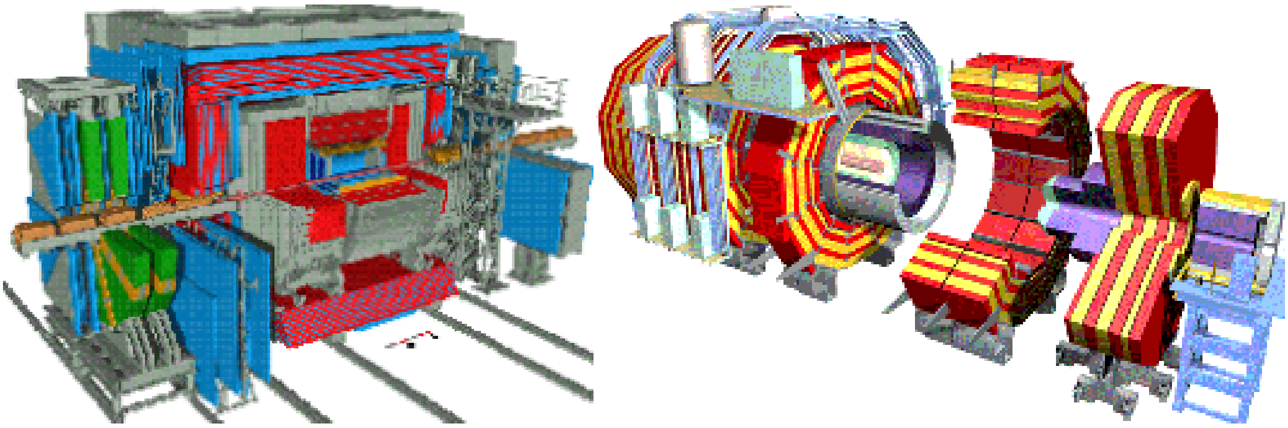
- Multichannel, distributed, synchronous measuring and control electronics systems:
  - Trigger Systems
  - Data Acquisition Systems (DAQ)
  - Monitoring and control System
  - Diagnostic and test Systems
- Data transmission Systems:
  - Optoelectronics links together with transmitter and receiver dedicated modules
  - Fast wire link transmission based on synchronous coded methods
  - Synchronous compression and decompression methods
- Steering and support software:
  - Dedicated object oriented software (C++, Scada etc)
  - Cooperation with data bases (servers, client tasks)
  - Steering and monitoring software based on computer network
- Specializations:
  - Programmable circuits (e. g. Altera, Xilinx)
  - Microprocessor circuits (e.g. DSP, interfaces etc)
  - Analog circuits (amplifiers, converters, shapers etc)
  - Parametric descriptions of electronics modules (VHDL, AHDL, Verilog)
  - Fast electrical and optical data links interfaces (also synchronous)

During the last several years members of these Groups participated in the following projects and work:
ZEUS Experiment at HERA accelerator (DESY, Hamburg) 1992-2002

I. BAC Detector

- BAC Triger Service System and energetic readout (2K channels)

- 13 VME 9HE PCBs for first level trigger of BAC detector
- 15 ME 9HE – *SCANNER* steering boards
- GFLT – *GFLTBI* interface



From left: ZEUS detector of HERA accelerator; CMS detector of LHC accelerator; Source: DESY and CERN web pages.

From upper left to lower down: Editors with a group of PERG.IES.WUT students; HERA Tunnel in DESY, Hamburg; ZEUS Detector Entrance and ZEUS Power Cabling.

- Position readout system for first stage trigger – 40K channels
    - 330 modules placed directly on ZEUS detector, 220 channels per each module – *HIT-BOX*
    - 25 communication boards VME 6HE – *CONTROLLER*
    - 5 cooperation boards with the first stage of the trigger VME 6HE - *DISTRIBUTOR*
- Testing system for detector electronics
    - 12 boards for programmable testing pulses, 40 channels per board VME 6HE – *PULSER*
    - 5 testing signal distribution boards VME 6HE – *SPLITTER*

II. VETO WALL Detector

- Background noise detecting system for each e-p collision in ZEUS detector
    - 6 signal detection modules for particle transfer in time slot, 32 channels VME 6HE – *CON6UR*
    - 1 programmable module for coincidence matrix discovering the paths of background particles (48 per 48 channels) - *CMATRIX*
- Data Readout System for VETO WALL detector for first stage trigger – 96 channels – *VETO HIT-READOUT*
- Programmable light pulser for scintillators – 192 channels – *LED-PULSER*

III. CMS Experiment at LHC accelerator (CERN, Genewa) 1996-2002
RPC Detector

- Participation in the design of muon trigger RPC – 200K channels
- System of fast, synchronous data transmission - 760 links
- Data readout system for first stage trigger – 200K channels
- Diagnostic and monitoring modules for RPC trigger - above 5K networked modules with supervision system

TESLA FUTURE

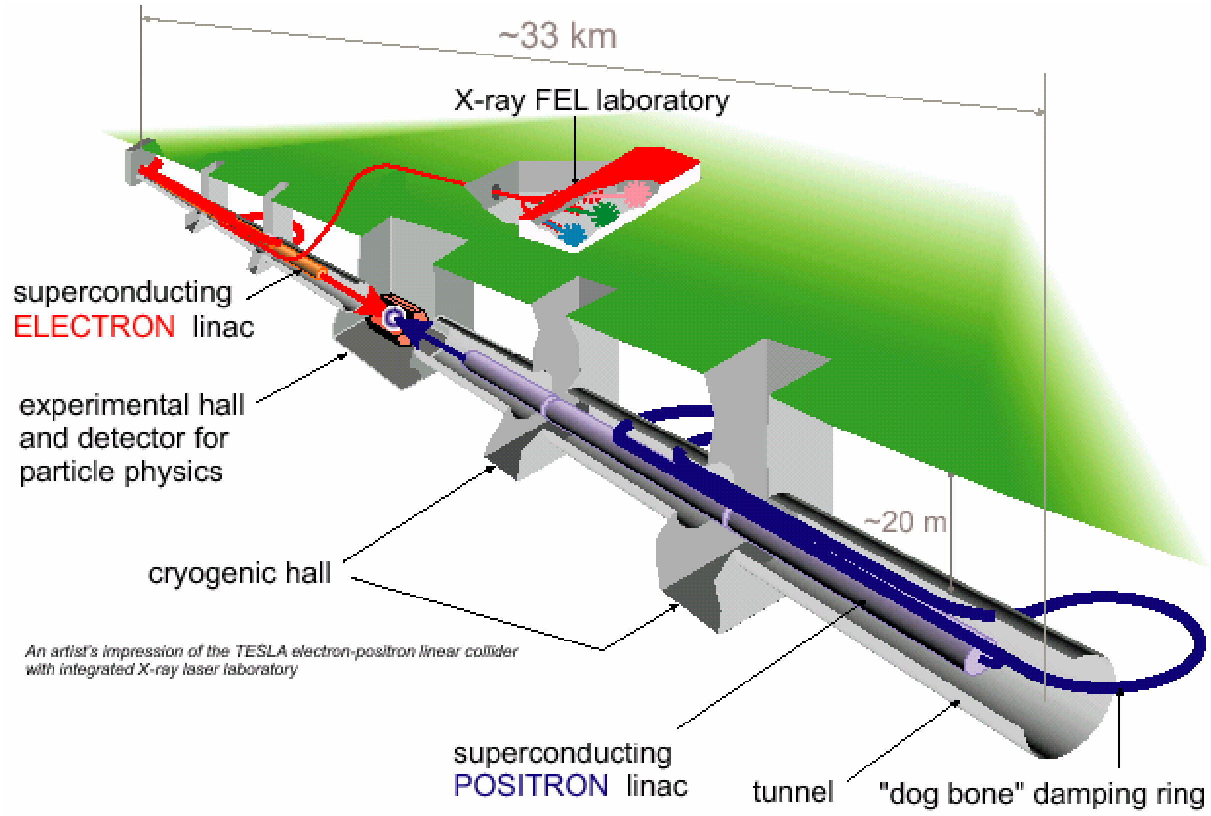
TESLA is a superconducting electron-positron collider with an initial centre of mass energy reach of 500 GeV, extendable to 800 GeV, and an integrated X-ray laser laboratory. A large-scale interdisciplinary and international research campus will be created around TESLA to provide unique research possibilities for particle physics, for condensed matter physics, chemistry and material science, and for structural biology. In this way TESLA satisfies the criteria for new large endeavours in science: they should be unique, open completely new research possibilities and should carry the promise to advance our knowledge of nature in many branches of science. The cost of the entire facility is approximately 3.8 billion EUR. The whole length of Tesla is ~33 km. The source for information in this chapter is Tesla TDR, available at tesla.desy.de. Short excerpts were taken and quoted here from this source.

At the heart of the TESLA linear collider are the two ~14km linear accelerators (linacs). It has long been acknowledged that superconducting (niobium) technology for the accelerating structures (cavities) offers many advantages over conventional warm (copper) structures:

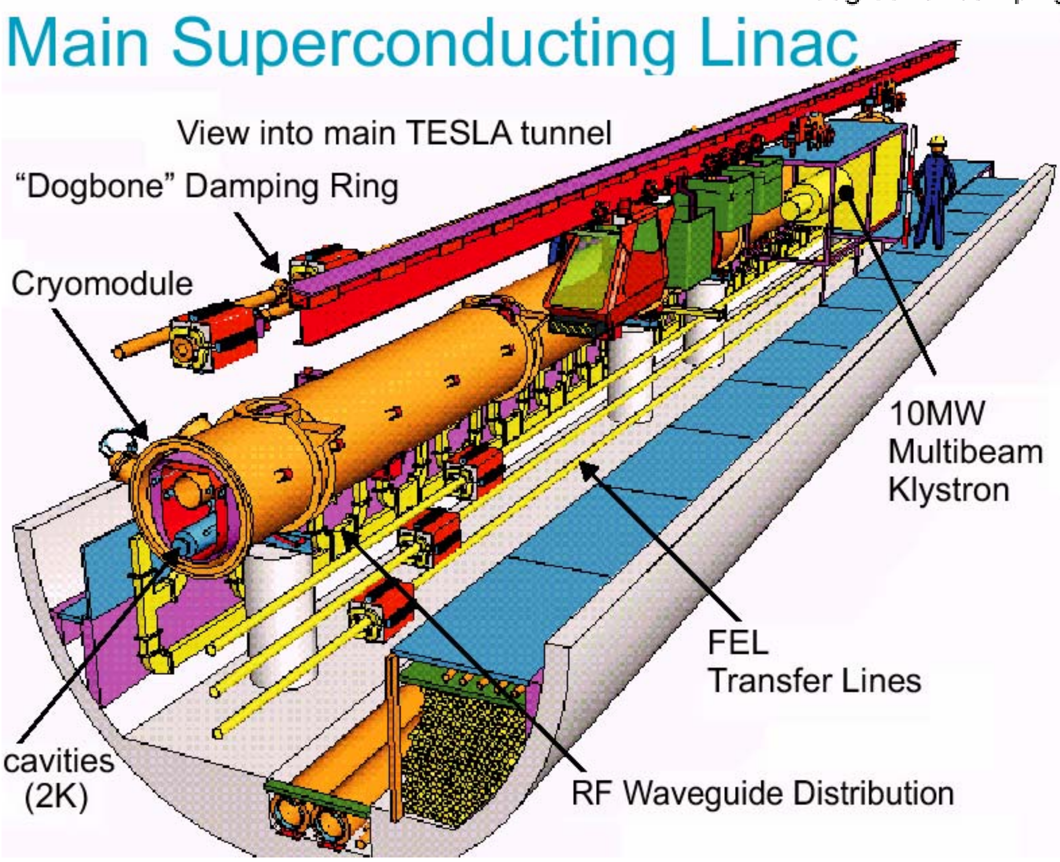
- the wavelength of the structures can be large (low frequency, 1.3 Ghz), significantly reducing the wakefields, resulting in relaxed cavity alignment tolerances; because the damping time of the cavities is essentially infinite, a long RF pulse (1.5 ms) can be used to feed power
- from a low (peak power) source; the losses in the walls of the cavities are extremely small, leading to a very high RF-to-beam power transfer efficiency; the long RF pulse allows a long bunch train (950 μs)

with many bunches (2820) and relatively large bunch spacing (337 ns). An inter-bunch trajectory correction (feedback) systems can therefore be used to stabilize the collisions at the interaction point.

Main parameters of Tesla Linac e^-e^+	I	II	units
Centre of mass energy at Interaction Point (IP)	2x250=500	800	GeV
Accelerating gradient at $T=2^oK$	23,4	35	MV/m
Total site length	33	33	km
No of accelerating structures (cavities)	21024		
Number of cavities per module	12		
Cavity finesse at $T=2^oK$	10^{10}		
No of klystrons (high power RF stations)	584	doubled	
Klystron peak power at 65% efficiency	9,5		MW
Number of quadrupoles	712		
Repetition rate	5	4	Hz
Beam pulse length	950	860	μm
No of bunches per pulse	2820	4886	
Bunch spacing	337	176	ns
Charge particles per bunch	2,0	1,4	x10E10
Pulse current	9,5	12,7	mA
Two-linac primary AC electric power	97	~150	MW
Power per beam	11,3		MW
Beam size at IP (width, height) (x,y)	553,5	391 / 2,8	Mm
Bunch length at IP	0,3	0,3	mm
Normalised transverse emittance at IP (x,y)	10 / 0,03	8 / 0,015	mm mrad
Beta function at IP (x,y)	15 / 0,4	15 / 0,4	mm
Beamstrahlung $\Delta P/P$	3,2	4,3	%
Vertical disruption D_y	25	27	
Luminosity	3,4x10E34	5,8x10E34	$cm^{-2}s^{-1}$
Main parameters of Tesla XFEL – linac; Source: Tesla TDR			
Linac optimized gradient for XFEL operation	18	MV/m	
Liniac repetition rate for XFEL	5	Hz	
Bunch length (rms)	80	Fs	
Bunch spacing (minimal pulse separation)	93	Ns	
Maximum number of bunches (pulses) per train	11500	#	
Bunch train length	1070	μs	
Bunch charge	1	NC	
Over-all power efficiency to electron beam	30	%	
XFEL parameters			
Energy	0,5 – 14,4	keV	
Wavelength (parameters are given for shortest λ)	0,85 – 25	Angstrom	
Saturation length	60-220	m	
Peak power	37-100	GW	
Average power	210-550	W	
Photon beam divergence (fwhm) (far field divergence)	0,8-6	μrad	
Photon beam diameter (fwhm) (undulator exit)	0,1-1	mm	
Bandwidth (fwhm)	0,08	%	
Coherence time	0,3	fs	
Pulse duration (fwhm)	100	fs	
Average flux of photons	$1,0*10^{17}$	#/sec	
Number of photons per pulse	$2 – 10*10^{12}$	#	
Peak brilliance	$8,7*10^{33}$	$sec*mrad^2*mm^2*0,1\%$ bandwidth	
Average brilliance	$4,9*10^{25}$	$sec*mrad^2*mm^2*0,1\%$ bandwidth	



An artist's impression of the TESLA electron-positron linear collider with integrated X-ray laser laboratory



LOW LEVEL RF CONTROL FOR TESLA

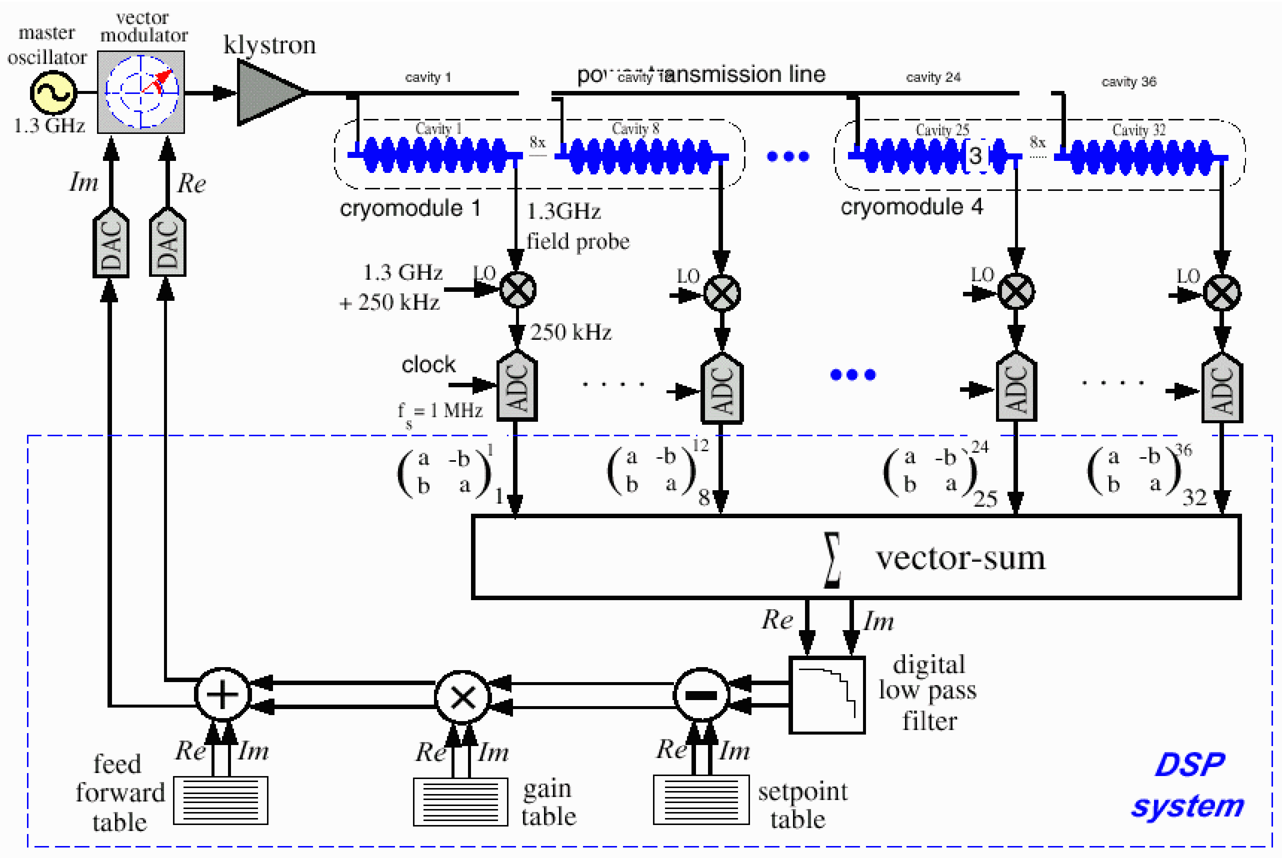
Tesla employs nine-cell cavities made of pure Niobium. Superconducting cavities exhibit a high susceptibility to mechanical perturbations due to the narrow bandwidth of the cavities. Significant phase and amplitude errors can be induced by the frequency variations excited by microphonics and Lorentz force detuning. The dynamical Lorentz force detuning of cavities operated in pulsed mode at high gradients (15MV/m) can approach the cavity bandwidth thereby demanding substantial additional power for field control. The LLRF control system should employ a completely digital feedback system to provide flexibility in the control algorithms, precise calibration of the vector-sum, and extensive diagnostics and exception handling capabilities. The LLRF system should provide amplitude and phase stability of the high power RF signal and enable calibration of the vector-sum. The particular requirements for Tesla are: keep bunch-to-bunch energy spread below intra-bunch energy spread of $5x10^{-4}$ (rms). Assuming suppression of correlated errors to $3x10^{-4}$ the uncorrelated requirements for Tesla are $5x10^{-3}$ for amplitude and $0,5^{o}$ for phase. Uncorrelated errors are suppressed by $N^{1/2}$, where N is the number of klystrons in the linac. The components of the vector-sum must be calibrated to better than 10% in amplitude of gradient and 1^{o} in phase for microphonic noise levels up to $\pm 10^{o}$. Apart form multiple feedbacks, the system possesses adaptive feed forward. AFF can handle nonlinear systems through liberalization around the operating point. Nonlinearity in Tesla in introduced by the propagating pulsed electron beam gaining efficiently energy from the HP RF field. It is expected that the AAF will be made by fast mechanical piezoelectric tuning system over-imposed on the cavities.

Contributions to the energy fluctuations are: Lorentz force; Microphonics; Bunch-to-bunch charge fluctuations; Calibration error of the vector-sum; Phase noise of the master oscillator; Non-linearity of field detector; Klystron saturation; RF curvature – finite bunch length; Wakefield and higher order modes (HOM).

Among the main goals of manufacturing such a large experimental sub-system there are cost reduction, to make it more compact and performance enhancement. Now with the advent of very powerful mega-gate FPGAs it is justified to make a feasibility study on the usage of programmable gate arrays in the RF control system of Tesla project. Next generation of FPGAs are predicted to be equipped with embedded DSP islands, which may further facilitate their usage in control engineering tasks. Ability to process large amounts of information by next generation FPGAs encourages the parallel architectures and cooperation with photonic and fast fibre optic systems. ELHEP Laboratory is involved in such work for Tesla.

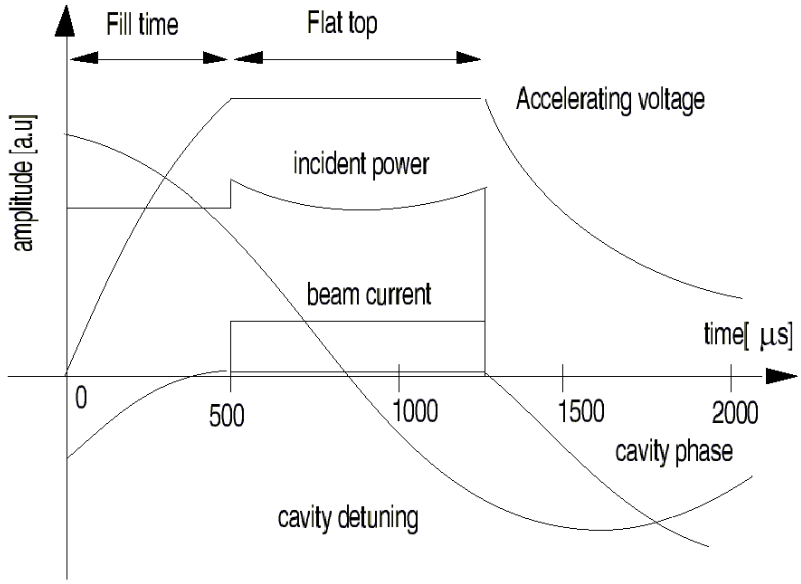
LLRFC parameter design stems from the requirements on eventual beam quality. The requirements for amplitude and phase stability of the vector-sum of 36 cavities are driven by the maximum tolerable energy spread in the beam. 36 cavities, organized in three cooled modules, are supplied by a single 10MW klystron. It is desirable to keep the bunch-to-bunch energy spread below the single-bunch energy spread of $5*10^{-4}$, in order to assure that the bunch-to-bunch chromatic effects will not be a dominant emittance growth factor. The bunch-to-bunch rms energy error due to systematic errors of all the klystrons can be suppressed to the level of $3*10^{-4}$. The tolerance for the uncorrelated random errors of each individual klystron is set such that the total rms error is not greater than the systematic error. If N_k is the number of klystrons per linac (N_k=280), then the maximum allowed uncorrelated error for each klystron is $N_k^{1/2}*3*10^{-4}$.

An important constraint is that the RF power needed for control should be minimized. The RF control system must also be robust against variations of system parameters such as beam loading and klystron gain, especially close to klystron saturation. The pulsed structure of the RF power and the beam current, imposes demanding requirements on the RF control system. Amplitude and phase control is obviously needed during the flat top of 950µs when the beam is accelerated, but it is equally desirable to control the field during cavity filling to ensure proper beam injection conditions and to minimize the RF power during filling.



Principle of LLRF control for Tesla; Source, tesla web: tesla.desy.de/Posters.html; tesla.desy.de/new_pages

ELHEP Research Group for TESLA; From left: I - Tomasz Jeżyński, Ph.D.student of PERG, dr Krzysztof Poźniak, dr Ryszard Romaniuk, dr Zbigniew Golebiewski - DESY, dr Stephan Simrock – LLRF TESLA project coordinator at DESY, dr Dieter Trines, deputy director of DESY; II – Tomasz Jeżyński, Arne Burghardt – ASKON, Zbigniew Gołębiewski, Stephan Simrock, Ryszard Romaniuk, Maciek Kudła, Tomasz Czarski, Wojciech Zabołotny, Krzysztof Kierzkowski, Photo made in front of Tesla main control room.



Parameters related to the pulsed cavity fields of TTF. Source: Tesla TDR at tesla.desy.de

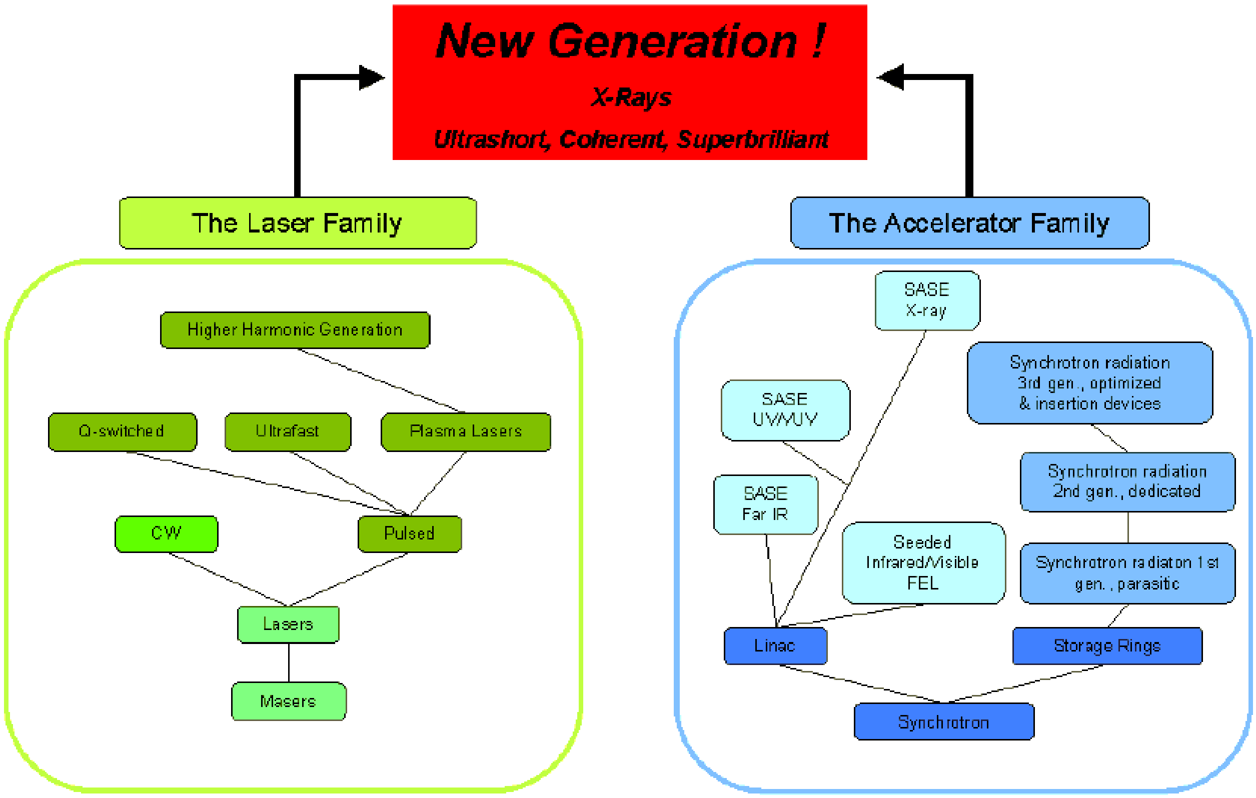
As a result of Lorentz force detuning and microphonics, the amplitude and phase errors are of the order of 5% and 20 degrees respectively. These errors must be suppressed by a factor of at least 10, and the loop gain must be adequate to meet this goal. Fortunately, the dominant source of errors is repetitive (Lorentz force and beam transients) and can be significantly reduced by the use of feed forward.

Fast amplitude and phase control of the cavity field can only be accomplished by modulating the signal driving the klystron, and hence systematically affects all the associated 36 cavities. A so-called I/Q modulator is used to control both the in-phase (I) and quadrature (Q) components of the cavity field. I and Q are the two Cartesian components of the cavity voltage, from which the amplitude and phase can be obtained. This scheme minimizes coupling between the loops and guarantees control in all four quadrants.

Digital I/Q detectors are used for the cavity field, incident and reflected waves. The RF signals are converted to an intermediate frequency of 250 kHz and sampled at a rate of 1 MHz (i.e. two consecutive data points describe I and Q of the cavity field). The I and Q components are multiplied by 2x2 rotation matrices to correct the phase offsets and to calibrate the gradients of the individual cavity probe signals. The vector-sum is calculated and corrected for systematic measurement errors. Finally the set point is subtracted and the compensator filter is applied to calculate the new actuator setting (I and Q control inputs to a vector modulator). Feed forward is added from a table in order to minimize the control effort. The feed forward tables are adaptively updated to reflect slowly changing parameters such as average cavity detuning, changes in klystron gain, phase shift in the feed forward path, and general changes in operating parameters. The operation of the more than 560 linac RF systems will be highly automated by the implementation of a finite state machine, which has access to high-level applications including the adjustment of the loop phase, vector-sum calibration, frequency and waveguide tuner control, and exception handling.

TESLA X-RAY FREE ELECTRON LASER

It is expected that the research in FELs and the development of accelerator based laser sources will bring together the development of so-called table-top lasers of different types. Optical, VUV and X-ray table-top sources are needed in pump-probe timing experiments and for home based test and preparation runs. The handling of spatially modulated tiny electron beams will advance today's techniques so far that even beam chirping can become feasible and lead the way to reduce the X-ray bunch duration towards 1 fs. The extremely high power density will open the fully new field of nonlinear X-ray phenomena and start experiments in X-ray quantum optics. It is even suggested that, with the high power levels generated by focusing, one could study the QED vacuum decay in high fields. Plasma physical phenomena will become accessible for the first time in a pressure-temperature region, which up to now cannot be prepared in the laboratory. The variety of new and exciting experimental possibilities in physics, chemistry, materials science, biology, and industrial applications should in fact lead to the same sort of revolutionary developments in X-ray studies of matter that was triggered in optical studies by introduction of the visible/UV lasers.



Is there a chance that, through the development of XFEL, two separate groups of laser will unite?

FEL versus optical laser

Radiation from a Free Electron Laser (FEL) has much in common with radiation from a conventional optical laser, such as: high power, narrow bandwidth and diffraction limited beam propagation. One of the main differences between the two lasers is the gain medium. In a conventional laser the amplification comes from the stimulated emission of electrons bound to atoms, either in a crystal, liquid dye or a gas, whereas the amplification medium of the FEL are "free" (unbound) electrons. The free electrons have been stripped from atoms in an electron gun and are then accelerated to relativistic velocities.

While the electrons are propagating through a long, periodic magnetic dipole array – so called undulator – the interaction with an electromagnetic radiation field leads to an exponential growth of the radiation emitted by the electrons. This amplification of radiation is initiated by an increasingly pronounced longitudinal density modulation of the electron bunch. The initial radiation field can be an external one, e.g. a seed laser, or an "internal" field, i.e. the spontaneous emission of the undulator. In the latter case it is called a SASE (Self Amplified Spontaneous Emission) FEL. Since the electrons in the FEL are not bound to atoms and thus not limited to specific transitions, the wavelength of the FEL is tunable over a wide range depending on accelerator energy and undulator parameters.

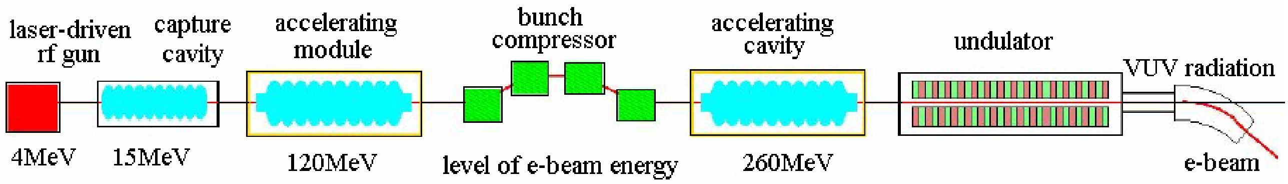
For IR, visible and UV FELs, light amplification can be reached in a multi-pass setup, i.e. by using an optical cavity with mirrors on both sides and the electrons passing the undulator as the gain medium in between. With such an arrangement, which – apart from its normally much larger size – exhibits a certain resemblance to optical laser setups, the light from many successive electron bunches is stored and amplified. For VUV and X-ray FELs, mirrors can no longer be applied due to their low reflectivities in normal incidence geometry at these wavelengths and potential mirror deformation/damage due to the high-absorbed powers. Since a SASE FEL operates in the high-gain regime, it does not require an optical cavity and it can hence be used to deliver light in the VUV and X-ray regime. In such a "single pass" SASE FEL the full radiation power builds up from spontaneous emission when an electron beam with high phase space density passes a long undulator just once. While FELs in the visible and UV range can also be realized in synchrotron radiation storage rings, there is a consensus that – due to the higher demands on the electron beam properties one needs a linear accelerator to generate FEL radiation in the VUV and X-ray range. The most promising approach is the setup of a single pass SASE FEL at a state of the art linear accelerator in combination with a high-performance radio frequency photo-cathode electron gun and longitudinal bunch compression to achieve the required peak current of several kA.

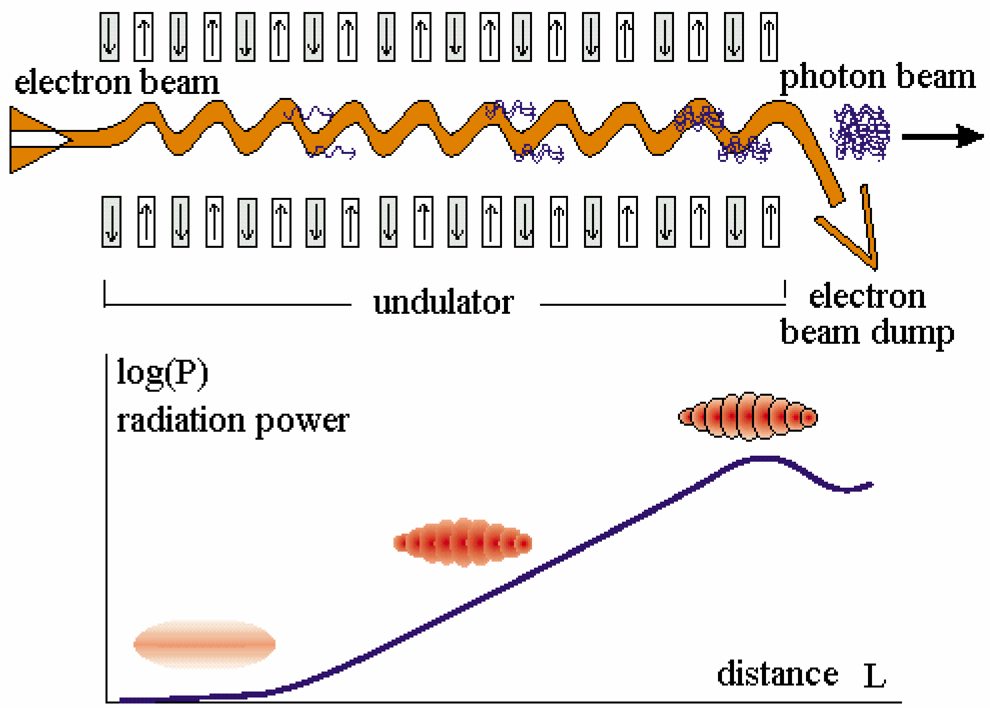
SASE FEL

The basic principle of the free electron laser can be described within the standard picture for the generation of synchrotron radiation. While traveling with relativistic velocity ($v \approx c$, $\gamma \approx 10^2 - 10^5$) through the undulator, the electrons are accelerated in the direction transverse to their propagation due to the Lorentz force introduced by the magnetic field. They propagate along a sinusoidal path and emit SR in a narrow cone in the forward direction. The typical opening angle of the wavelength integrated radiation is $1/\gamma = m_e c^2/E_e$, where m_e is the electron mass (511 keV/c^2) and E_e the electron energy. In the undulator, the deflection of the electrons from the forward direction is comparable to the opening angle of the synchrotron radiation cone. Thus the radiation generated by the electrons while traveling along the individual magnetic periods overlaps. This interference effect is reflected in the formula for the wavelength λ_{ph} of the first harmonic of the spontaneous, on-axis undulator emission $\lambda_{ph}= (\lambda_u/2\gamma^2)(1+K^2_{rms})$, where λ_u is the length of the magnetic period of the undulator and K_{rms} is the "averaged" undulator parameter $K_{rms}=eB_u\lambda_u/2\pi m_e c$, which gives the ratio between the average deflection angle of the electrons and the typical opening cone of the synchrotron radiation. B_u is the rms magnetic field of the undulator and e the electron charge. For planar undulator and sinusoidal magnetic field $K=2^{1/2}K_{rms}$ and in equation for K_{rms} B_u should be replaced by peak magnetic field B_o, thus $K=eB_o\lambda_u/2\pi m_e c$.

The interference condition basically means that, while travelling along one period of the undulator, the electrons slip by one radiation wavelength with respect to the (faster) electromagnetic field. This is one of the prerequisites for the SASE process of the FEL. To obtain an exponential amplification of the spontaneous emission present in any undulator, some additional criteria have to be met: One has to guarantee a good electron beam quality and a sufficient overlap between radiation pulse and electron bunch along the undulator. To achieve that, one needs a low emittance, low energy spread electron beam with an extremely high charge density in conjunction with a very precise magnetic field and accurate beam steering through a long undulator.

Oscillating through the undulator, the electron bunch then interacts with its own electro-magnetic field created via spontaneous emission. Depending on the relative phase between radiation and electron oscillation, electrons experience either a deceleration or acceleration: Electrons that are in phase with the electromagnetic wave are retarded while the ones with opposite phase gain energy. Through this interaction a longitudinal fine structure, the so called micro-bunching, is established which amplifies the electromagnetic field.





SASE in an undulator results from the interaction of the electrons with the synchrotron radiation they emit. Longitudinal density modulation (micro-bunching) of the electron bunch is combined with exponential growth of the radiation power along the undulator.

The longitudinal distribution of electrons in the bunch is “cut” into equidistant slices with a separation corresponding to the wavelength λ_{ph} of the emitted radiation, which causes the modulation. More and more electrons begin to radiate in phase, which results in an increasingly coherent superposition of the radiation emitted from the micro-bunched electrons. The more intense the electromagnetic field gets, the more pronounced the longitudinal density modulation of the electron bunch and vice versa.

In the beginning – without micro-bunching – all the N_e electrons in a bunch ($N_e>10^9$) can be treated as individually radiating charges with the power of the spontaneous emission prpoprtional to N_e. With complete micro-bunching, all electrons radiate almost in phase. This leads to a radiation power proportional to N_e^2 and thus an amplification of many orders of magnitude with respect to the spontaneous emission of the undulator. Due to the progressing micro-bunching, the radiation power $P(z)$ of such a SASE FEL grows exponentially with the distance z along the undulator: $P(z)=AP_{in}\exp(2z/L_g)$, where L_g is the field gain length, P_{in} the "effective" input power, and A the input coupling factor. A is equal to 1/9 in one-dimensional FEL theory with an ideal electron beam. For the estimation of the effective input power of the shot noise P_{in} one can use the spontaneous radiation power on the first gain length inside a coherence angle and within the FEL bandwidth. The exponential growth takes place until the electron beam is completely bunched after which it is overmodulated resulting in saturation.

The main properties of the FEL radiation can be simply estimated in terms of the FEL parameter ρ. The field gain length is $L_g \approx \lambda_u/4\pi\rho$, the FEL amplifier bandwidth $\Delta\omega/\omega$ and saturation efficiency (ratio of the output radiation power to the electron beam power) are about ρ . This parameter depends on the parameters of electron beam and undulator and is always much smaller than unity (for the TESLA XFELs ρ ranges between 10^{-3} and 10^{-4}).

The radiation from an X-ray FEL has a narrow bandwidth, it is fully polarized and transversely coherent. The transverse coherence is also reflected in the development of the transverse intensity distribution along the undulator, which in the end is nearly Fourier transform limited.

On the other hand, compared to conventional optical lasers the longitudinal coherence of an X-ray SASE FEL is rather poor which is a consequence of the start-up from shot noise. The coherence time is defined by the inverse spectral width $\Delta\omega$ and is for XFELs typically much smaller than the electron pulse duration. To improve the longitudinal coherence length, at best up to the full radiation pulse length, a so called "two-stage SASE FEL" is proposed, where the final output radiation bandwidth is close to the limit given by the finite duration of the pulse.

The temporal and spectral structure of the radiation pulse consists of a large number of independent wavepackets which give rise to "spikes". Within one wavepacket, the radiation is transversely and longitudinally coherent. The chaotic nature of the output radiation is a consequence of the start-up from shot noise: since the electron bunch consists of discrete charges randomly emitted from a cathode, the charge density exhibits fluctuations which are random in time and space. As a result, the radiation produced by such a beam has random amplitudes and phases in time and space. These kinds of radiation fields can be described in terms of statistical optics with, e.g., the following parameters: time and spectral correlation functions, transverse correlation functions, probability density distributions of the instantaneous radiation intensity, of its integrals (finite-time and space) and of the energy after a monochromator, coherence time, interval of spectral coherence, coherence area and coherence volume.

Using a planar undulator, a SASE FEL also naturally generates higher harmonics, since the micro-bunching of the electrons at the fundamental wavelength of the undulator can also drive substantial bunching at the higher harmonics. Simulations yield a significant power output of a high-gain SASE FEL which for the third harmonic amounts to several per thousand up to one percent of the first harmonic output power. Whereas this nonlinear generation of higher harmonics might be quite relevant when extending the FEL operation range to even shorter wavelengths, all quantitative examples in the scientific case are based on the first harmonic of the XFELs. This generation of higher harmonics should not be confused with high gain harmonic generation (HGHG) for FELs. Whereas the mechanism is identical, the HGHG consists of an undulator setup creating a micro-bunching at the first harmonic and a second undulator optimized for a higher harmonic which uses the density-modulated bunch to drive the modulation at this higher harmonic.

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