2005 FREQUENCY CONTROL - PTTI TUTORIALS
Sunday, 28 August 2005

This year the Tutorials will be held on Sunday, August 28th from 8:15AM until 5:45PM. Our tutorial leaders have been selected from among the best experts in the world. The tutorial presentations are designed for newcomers to the field, as well as containing state-of-the-art material for experienced practitioners desiring to keep up-to-date. The attendance at each tutorial will be recognized with Continuous Education Units (CEUs) to help maintain the Professional Engineer (PE) License. We look forward to your participation.

A single registration fee will allow attendees to participate in the Tutorials, in all of the sessions, and includes lunch as well as morning and afternoon refreshment breaks, and a CD containing copies of the tutorial presentations. The advanced registration fee for IEEE members and non-members is $225 US, if received no later than 12 August, and $250 US for on-site registration. The registration fee for FULL-TIME students and FULL-TIME retirees is $50 US. All registration fees MUST BE PAID IN US DOLLARS. In order to receive the reduced rate, you must submit your payment with your registration form. A limited number of additional copies of the instructional material (CD only) will be available at a cost of $75 US at the registration desk.

Tutorials on the Web
The slides from previous tutorial presentations may be viewed http://www.ieee-uffc.org/fc.

TUTORIAL SCHEDULE			
8:15AM - 10:15AM	**1A - Phase Noise I: Basics of Phase Noise** *Enrico Rubiola* *Universite' Henri Poincare', France*	**1B - Introduction to Quartz Frequency Standards** *John R. Vig* *US Army Communications-Electronics RDEC, USA*	**1C - Passive Atomic Frequency Standards** *Len Cutler* *Agilent Laboratories, USA*
10:15AM - 10:30AM	**Break**	**Break**	**Break**
10:30AM - 12:30PM	**2A – The Leeson Effect: Phase Noise and Frequency Stability Mechanisms in Oscillators** *Enrico Rubiola* *Universite' Henri Poincare', France*	**2B – Wireless Passive SAW Identification Marks and Sensors** *Leo Reindl,* *Albert-Ludwigs-Universität Freiburg, Germany*	**2C - Time Scales and Algorithms** *Patrizia Tavella* *Istituto Elettrotecnico Nazionale, Italy*
12:30PM - 1:30PM	**Lunch**	**Lunch**	**Lunch**
1:30PM - 3:30PM	**3A - Optical Schemes for Generation of Spectrally Pure Microwave Signals** *Lute Maleki* *Jet Propulsion Laboratory, USA*	**3B - Microelectromechanical Systems (MEMS) for Frequency and Timing References** *Clark T.-C. Nguyen* *DARPA/MTO, USA*	**3C - Time and Frequency Transfer** *Judah Levine* *National Institute of Standards & Technology (NIST), USA*
3:30PM - 3:45PM	**Break**	**Break**	**Break**
3:45PM - 5:45PM	**4A - Optical Measurement & Synthesis** *Thomas Udem* *Max Planck Institute, Germany*	**4B - Digital Measurement of Precision Oscillators** *Samuel. R. Stein* *Timing Solutions Corporation, USA*	**4C - The Role of Time and Frequency in GPS** *Joe White* *Naval Research Lab, USA*

Tutorial Session 1A - Phase Noise I: Basics of Phase Noise

Enrico Rubiola, Universite' Henri Poincare', France

This tutorial describes the practical aspects of phase and amplitude noise measurements. Basic measurements as well as advanced measurement techniques will be discussed. The use of PM and AM noise standards and wide-band modulators for system calibration is discussed. Two channel systems for AM and PM noise measurements that have noise floors approaching -195 dBc/Hz will be described.

Tutorial Session 2A – The Leeson Effect: Phase Noise and Frequency Stability Mechanisms in Oscillators

Enrico Rubiola, Universite' Henri Poincare', France

When phase noise is introduced in the loop of an oscillator, the oscillator converts it to frequency noise. The consequence is that the output phase noise of the oscillator increases dramatically in the long run. This phenomenon is generally referred to as the Leeson Effect after a short paper entitled: "A Simple Model for Feedback Oscillator Noise" published by David B. Leeson in 1966.

The first part of this tutorial explains the phase-to-frequency conversion mechanism as a general phenomenon inherent in the feedback, following a heuristic approach based on physical insight. The tutorial then follows with the relationships between the noise of the internal components (sustaining amplifier, resonator, etc.) and the phase noise at the oscillator output or equivalently the frequency stability.

The second part of this tutorial presents the analysis of the phase noise spectra found in the data-sheet of commercial oscillators, dielectric-resonator oscillator (DRO), whispering gallery oscillator (WGO), 5-100 MHz quartz crystal oscillators, and opto-electronic oscillator (OEO). The analysis presents information on the most relevant design parameters like the merit factor Q and the driving power of the resonator and the flicker noise of the sustaining amplifier.

The final part of this tutorial shows the derivation of the phase noise formulae from the elementary properties of the resonator. This approach is general, thus it applies to all oscillators (quartz, RLC, microwave cavity, delay-line, laser, etc.).

Enrico Rubiola is scientist at the Department of Physics and Metrology of Oscillators of the FEMTO-ST Institute, a government research laboratory, and a professor of electronics at the Université de Franche Comté, Besançon, France. Formerly, he had been a professor at the Université Henri Poincaré, Nancy, France, a professor at the Università di Parma, Italy, and a researcher at the Politecnico di Torino (the technical university of Torino), Italy. He graduated in electronic engineering at the Politecnico di Torino in 1983 with a thesis on land-vehicle navigation, received the PhD in Metrology from the Italian Ministry of University and Research, Roma, in 1989 with a thesis on clock comparison, and received the Doctor of Science degree from the Université de Franche Comté in 1999 with a thesis on time and frequency metrology.

Prof. Rubiola has worked on various topics of electronics and metrology, namely, navigation systems, time and frequency comparisons, atomic frequency standards and gravity. His main fields of interest are precision electronics form dc to microwaves and phase noise metrology, which include frequency synthesis, high spectral purity oscillators, photonic systems, and noise. In the domain of phase noise, he has developed a new generation of instruments with ultimate sensitivity, based on synchronous detection of the error signal in a sophisticated version of the Wheatstone bridge, and on a variety of signal-processing methods.

Numerous articles, reports and conference presentations are available on the Enrico Rubiola's home page http://rubiola.org.

Tutorial Session 3A - Optical Schemes for Generation of Spectrally Pure Microwave Signals

Lute Maleki, Jet Propulsion Laboratory, USA

Optical schemes have been recently developed to effectively meet the challenge of spectrally puree signal generation in the microwave domain. This is a growing area of interest associated with a general desire to develop high performance communications and radar systems at frequencies in the range of 10 to 100 GHz.

In this tutorial a review of various schemes for generation of ultra-high spectrally pure microwave signals will be made. The aim is to discuss various approaches, and identify the strengths and shortcomings of each scheme. The tutorial will be self-contained; no familiarity will optical schemes will be assumed.

Lute Maleki is a principle member of the technical staff and the Technical Group Supervisor of the Time and Frequency Science and Technology Group at JPL. His current research interest include ion confinement and trapped ion frequency standards, development of laser-cooled atom traps, study of various aspects of the physics of frequency standards, photonics reference frequency generation and distribution, investigations of the noise and stability properties of rf and optical frequency sources, and test of fundamental laws of physics using atomic clocks. He received his B.S. in Physics from the University of Alabama in 1969 and his Ph.D. in Experimental Atomic Physics in 1975 from the University of New Orleans (Louisiana State Universities). Dr. Maleki is a member of the American Physical Society, and the Optical Society of America and a Fellow of the IEEE.

Tutorial Session 4A - Optical Measurement & Synthesis

Thomas Udem, Max Planck Institute, Germany

A femtosecond frequency comb is a versatile tool to phase-coherently-connect vastly different frequency regions. For the construction of an all optical clock, the conversion from optical frequencies to the radio frequency domain is essential, but conversions between different optical frequencies are also possible. This tutorial will cover the derivation of the frequency comb properties as well as their generation. An overview of applications will be given as well.

Thomas Udem studied from 1987 to 1993 at the University of Giessen/Germany and at the University of Washington in Seattle/USA. In 1993, he received his diploma from the University of Giessen. After that he was working towards the PhD at the Max-Planck-Institut fuer Quantenoptik in Garching/Germany which he received from the Ludwigs Maximilians Universitaet Munich/Germany in 1997. Since then he has been working at the Max-Planck Institut fuer Quantenoptik and at the National Institute for Standards and Technology in Boulder/USA. In 2004, he received his habilitation from the Ludwigs Maximilians Universitaet.

Tutorial Session 1B - Introduction to Quartz Frequency Standards

John R. Vig, US Army Communications-Electronics RDEC, USA

The subject of quartz frequency standards will be reviewed. Emphasis will be on those aspects, which are of greatest interest to users (as opposed to designers). The discussion will include:

- crystal resonator and oscillator basics;
- the characteristics and limitations of temperature compensated crystal oscillators (TCXOs) and oven controlled crystal oscillators (OCXOs);
- oscillator instabilities: aging; noise; and the effects on frequency stability of: temperature, acceleration, radiation, warm-up, pressure, magnetic field, and the oscillator circuitry;
- guidelines for oscillator comparison, selection and specification.

A preview of this tutorial can be found on the web at: http://www.ieee-uffc.org/fc

John R. Vig was born in Hungary in 1942. He immigrated to the United States in 1957, received the B.S. degree in physics from the City College of New York in 1964, and the M.S. and Ph.D. degrees from Rutgers - The State University, New Brunswick, NJ in 1966 and 1969, respectively. Since 1969 he has been employed as a research scientist and program manager in a US Army research laboratory, working primarily on the experimental aspects of frequency control devices. He has published more than 100 papers and book chapters, and has been awarded 54 patents.

John was President of the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society (UFFC-S) in 1998-99, and was also the founding President of the IEEE Sensors Council. In 1988, John was elected a Fellow of the IEEE "for contributions to the technology of quartz crystals for precision frequency control and timing." He received the 1990 IEEE Cady Award "for outstanding contributions to the development of improved quartz crystals and processing techniques..." He was the UFFC-Society's Distinguished Lecturer for 1992-93, served as the General Chairman from 1982 to 1988 of what is now the IEEE Frequency Control Symposium. He was Chair of the Symposium Technical Program Committee in 2002; he has served as a member of the Committee since 1972. He has also served on the Technical Program Committee of the IEEE Ultrasonics Symposium since 1986. He was twice elected to the IEEE UFFC-Society Administrative Committee, for the 1986-89, and 1995-98 terms. He was awarded the UFFC-S' highest award, the Achievement Award, in 2001. He served on the Board of Directors of the IEEE in 2002-2003, and was elected to serve as the 2005 Vice-President for IEEE Technical Activities.

Tutorial Session 2B – Wireless Passive SAW Identification Marks and Sensors

-- Leo Reindl, Albert-Ludwigs-Universität Freiburg,Germany

In the recent years wireless SAW sensors and identification tags have come under notice with a growing number of publications and applications. In this tutorial the operating principles of wireless passive SAW based identification marks and sensors are reviewed. The whole radio sensor system consists of a read-out unit, comparable to an RADAR device, and a passive transponder, consisting of a surface acoustic wave (SAW) device wired to an antenna. The surface acoustic wave stores the read-out signal for a predefined period of time to suppress all environmental echo interferences. Physical or chemical effects may influence the propagation characteristics of the surface acoustic wave. Two fundamental devices allow storing and modulating of surface acoustic waves: the resonator, and the uniform or chirped delay line.

In this tutorial, the transponder setup using a reflective delay line, resonator, or impedance sensor is discussed in detail, as well as the setup of the read out unit using a pulse or FMCW radar. Special emphasis is set on the achievable accuracy and on the sensitivity range. Several applications of such sensor systems and their state-of-the-art performance is presented by way of examples which include identification marks and wireless measurements of temperature, pressure, torque, acceleration, tire-road friction, magnetic field, and water content of soil. A discussion of other resonant structures which also could be used in a passive transponder system will close the tutorial.

Leonhard Reindl received the Dipl. Phys. degree from the Technical University of Munich, Germany in 1985 and the Dr. sc. techn. degree from the University of Technology Vienna, Austria in 1997. From 1985 to 1999 he was a member of the micro acoustics group of the Siemens Corporate Technology department, Munich, Germany, where he was engaged in research and development on SAW convolvers, dispersive and tapped delay lines, ID-tags, and wireless passive SAW sensors. In winter 1998/99 and in summer 2000 he was guest professor for spread spectrum technologies and sensor techniques at the University of Linz, Austria. From 1999-2003 he was university lecturer for communication and microwave techniques at the Institute of Electrical Information Technology, Clausthal University of Technology. In May 2003 he accepted a full professor position at the laboratory for electrical instrumentation at the Institute for Micro System Technology (IMTEK), Albert-Ludwigs-University of Freiburg.

His research interests include wireless sensor and identification systems, surface acoustic wave devices and materials, as well as microwave communication systems based on SAW devices. He holds 35 patents on SAW devices and wireless passive sensor systems and has authored or co-authored approximately 130 papers in this field.

Leonhard Reindl is Elected Administrative Committee (AdCom) - member of the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society and also member in the Microwave Theory and Techniques society. Since 2000 he is member of the Technical Program Committee of the IEEE Frequency Control Symposium. He is also engaged in technical committees of the German VDE/ITG Association, and serves as chairman for the German conference "Sensors and Measurement Systems 2006".

Tutorial Session 3B - Microelectromechanical Systems (MEMS) for Frequency and Timing References

Clark T.-C. Nguyen, DARPA/MTO, USA

Microelectromechanical systems (MEMS) technology harnesses micro-scale miniaturization to affect the same scaling advantages of faster speed, lower power consumption, lower cost, and smaller size, enjoyed for decades by transistor electronics, but for devices with mechanical operating principles. Devices based on microelectromechanical systems (MEMS) technology have now found their way into numerous commercial applications, from pressure sensors for blood pressure monitors, to accelerometers for automobile air bag deployment, to mirror arrays for high resolution laptop projectors. Recent advances in micromechanical vibrating resonator technology that have yielded tiny on-chip devices that resonate at GHz frequencies with Q's 10,000 now create new opportunities for precise, low-noise frequency shaping and generation where massive numbers of high-Q resonators can be used to attain unprecedented robustness, sensitivity, and power economy for portable wireless devices. And as these devices make their way into products, research efforts aimed at applying to MEMS technology towards even better portable timing stability are presently underway. In particular, work towards chip-scale atomic clocks has now achieved physics packages in volumes less than 10 mm3, yet still with stabilities on the order of 3x10-10 at 1s, and all this still very early in the DARPA program fueling this research.

This course presents an overview of the mechanical devices and associated technologies expected to play key roles in making available tiny, truly portable frequency and timing references for future communications, GPS, and sensing applications. It begins with reviews on the fabrication technologies that make MEMS possible, then proceeds to cover in succession: (1) vibrating micromechanical resonator development over the years; (2) micromechanical resonator oscillators; (3) micromechanical filters; and (4) the latest in progress on chip-scale atomic clocks.

Clark T.-C. Nguyen is the Program Manager of the Microelectromechanical Systems (MEMS), Micro Power Generation (MPG), Chip-Scale Atomic Clock (CSAC), MEMS Exchange (MX), Harsh Environment Robust Micromechanical Technology (HERMIT), Micro Gas Analyzers (MGA), and Radio Isotope Micropower Sources (RIMS) Programs in the Microsystems Technology Office of DARPA. Dr. Nguyen received the B.S., M.S., and Ph.D. degrees from the University of California at Berkeley in 1989, 1991, and 1994, respectively, all in Electrical Engineering and Computer Sciences. In 1995, he joined the faculty of the University of Michigan, Ann Arbor, where he is presently on Leave from an Associate Professor position in the Department of Electrical Engineering and Computer Science. From 1995 to 1997, he was a member of the National Aeronautics and Space Administration (NASA)'s New Millennium Integrated Product Development Team on Communications, which roadmapped future communications technologies for NASA use into the turn of the century. During his period with the University of Michigan, his technical interests focused upon micro electromechanical systems and included integrated vibrating micromechanical signal processors and sensors, merged circuit/micromechanical technologies, RF communication architectures, and integrated circuit design and technology. He has more than 92 publications and holds 16 patents on this subject matter. In his faculty position, Dr. Nguyen received the 1938E Award for Research and Teaching Excellence from the University of Michigan in 1998, an EECS Departmental Achievement Award in 1999, the Ruth and Joel Spira Award for Outstanding Teaching in 2000, and the University of Michigan's Henry Russell Award in 2001. Together with his students, he received the Roger A. Haken Best Student Paper Award at the 1998 and 2003 IEEE International Electron Devices Meeting's for work on the first micromechanical mixler: a device capable of both low-loss mixing and filtering for communications in a single passive micromechanical structure; and for work on the extensional wine-glass micromechanical ring resonator, capable of vibrating at GHz frequencies with Q's in the 1,000's. In 2001, Dr. Nguyen founded Discera, Inc., a company aimed at commercializing communication products based upon MEMS technology, with an initial focus on the very vibrating micromechanical resonators pioneered by his research in past years. He served as Vice President and Acting Chief Technology Officer (CTO) of Discera from 2001 to mid-2002.

Tutorial Session 4B - Digital Measurement of Precision Oscillators

Samuel R. Stein, Timing Solutions Corp., USA

This tutorial reviews the subject of digital measurements of clocks and oscillators. It focuses primarily on the precision measurement of phase and the use of these measurements in estimating phase and frequency and common statistics such as the Allan deviation and the spectral density of phase. The subject matter includes direct counting, interpolating counters, dividers, heterodyne conversion, and dual-mixer systems. Biases in the measurements caused by aliasing and measurement quantization are evaluated. Analog techniques, which are used primarily to evaluate phase noise, are covered in a related tutorial.

Samuel R. Stein is founder and President of Timing Solutions Corporation, a company that specializes in real-time applications and that provides timing systems to National Laboratories, DoD programs such as GPS, and Government Prime Contractors. He has developed ultra high precision time measurement, generation and distribution systems and is an internationally recognized leader in time and frequency measurement methods and the ensembling of clocks. He was previously Technical Director at Ball Corporation (Efratom Division) and Time and Frequency Division Chief at the National Bureau of Standards (NIST). Dr. Stein has more than 48 publications and eight patents.

Tutorial Session 1C - Passive Atomic Frequency Standards

Len Cutler, Agilent Laboratories, USA

This tutorial will cover much of the basic physics and electronics of passive atomic frequency standards. Particular attention will be paid to the design aspects that affect the accuracy and frequency stability of the standards and ways to optimize the performance. The cesium atomic beam standard will be treated in the most detail.

Leonard S. Cutler received the PhD degree in theoretical physics from Stanford University in 1966. He has been heavily involved in the theory and design of atomic frequency standards and precision quartz oscillators since 1957. His present position is Distinguished Contributor, Technical Staff, Agilent Laboratories.

Tutorial Session 2C - Time Scales and Algorithms

Patrizia Tavella, Istituto Elettrotecnico Nazionale, Italy

Time Scales: keeping time and the new most demanding applications. The tutorial will deal with the definition and realization of a time scale as a system for timekeeping, but also it will consider the new demanding applications such as satellite systems and telecommunication networks where the mathematical model of the clock errors and their statistics are fundamental information.

Patrizia Tavella, degree in Physics and Ph.D. in Metrology, is now with the Istituto Elettrotecnico Nazionale, Torino, Italy in the Time Metrology Dept. Her main interests are mathematical and statistical models mostly applied to atomic time scale algorithms and to the uncertainty evaluation of atomic clock measurements. She is involved in the European project Galileo for the development of a satellite navigation system and she chairs the CCTF WGs on TAI and on Algorithms.

Tutorial Session 3C - Time and Frequency Transfer

Judah Levine, National Institute of Standards & Technology (NIST), USA

In this tutorial I will discuss the different methods of transmitting time and frequency information. All of the methods that I will discuss are based on 3 fundamental techniques: (1) transmitting signals in one direction between an active transmitter and a passive receiver, (2) two-way transmissions between stations both of which are active and (3) common-view methods based on more than one passive receiver listening to the signals from one transmitter. I will compare the capabilities of these techniques in principle, and I will illustrate these capabilities using examples derived from systems that currently use each of these techniques. I will then turn to a more detailed discussion of the methods that are in common use, including those that use the telephone system, the Internet, radio broadcasts, and both active and passive satellite systems. Finally, I will introduce the various methods of disciplining a local oscillator – that is, what to do with the time information after it has been received. Since this is a very broad topic, I welcome suggestions (sent to jlevine@boulder.nist.gov) on areas of special interest to the attendees, and I will try to address these interests in my presentation.

Judah Levine received his Ph.D. in Physics from New York University in 1966. After post-doctoral work at the Clarendon Laboratory of Oxford University and the Joint Institute for Laboratory Astrophysics in Boulder, he joined the staff of the National Bureau of Standards in 1969. He joined the Time and Frequency Division of NBS in 1972, and has worked on time scales, on the statistics of clocks and oscillators, and on the definition, realization, and distribution of UTC and UTC (NIST) since that time. He has also worked on instruments and methods for detecting gravitational waves, for studying the dynamics of seismic zones, and for measuring long baselines to very high accuracy. Dr. Levine is a member of the IEEE and a Fellow of the American Physical Society.

Tutorial Session 4C - The Role of Time and Frequency in GPS

Joe White, Naval Research Lab, USA

The Global Positioning System is best known as a navigation system that will also do time dissemination. Those who know GPS will tell you that it is really a time comparison system that can do navigation. Precise clocks are the heart of GPS. Ranges from the GPS satellites to the user receivers are based on precisely measuring the time difference between the receiver's clock and the GPS satellite clock.

This tutorial will present GPS first as a history of the technology that has made it work and then describe the critical time and frequency elements of the system as it is today with some projections on the future.

Joe White received his BS in Physics in 1969 from Western Kentucky University; his MS in 1974 and his PhD in 1981 in Physics from American University. He's worked as a Research Physicist since 1973 at the Space Applications Branch of the U.S. Naval Research Laboratory. He is currently the head of the Advanced Technology Section with responsibility for GPS space clock development, space GPS receivers, GPS receiver testing and calibration, applications of GPS to military timing systems, precision clock testing, and environmental testing of clocks and timing hardware. Dr. White is the Chairman of the Executive Board for the Precise Time and Time Interval Systems and Applications Meeting (PTTI) and a Member of IEEE Frequency Control Symposium Technical Program Committee.