30TH ANNUAL PRECISE TIME AND TIME INTERVAL (PTTI) SYSTEMS AND APPLICATIONS MEETING

Editor
Lee A. Breakiron
U.S. Naval Observatory

Proceedings of a meeting sponsored by
the U.S. Naval Observatory
the U.S. Naval Research Laboratory
NASA Headquarters
the NASA Jet Propulsion Laboratory
the Defense Information Systems Agency
The U.S. Marine Corps
the Space and Naval Warfare Systems Command
the Air Force Office of Scientific Research
the U.S. Air Force Space Command
and the U.S. Coast Guard Navigation Center

and held at
the Hyatt Regency Hotel
Reston, Virginia
1 — 3 December 1998

United States Naval Observatory
Washington, DC 20392-5420

1999

EXECUTIVE COMMITTEE

DR. JOSEPH D. WHITE, CHAIRMAN
U.S. Naval Research Laboratory

CAPTAIN BRENT K. ANDBERG
U.S. Marine Corps.

MR. RONALD L. BEARD
U.S. Naval Research Laboratory

DR. LEE A. BREAKIRON
U.S. Naval Observatory

CAPTAIN JAMES T. DOHERTY
U.S. Coast Guard

DR. HELMUT HELLWIG
Deputy Assistant Secretary Air Force/AQR

MAJOR PETER INGENLOFF
U.S. Air Force

MR. PAUL F. KUHNLE
NASA Jet Propulsion Laboratory

DR. DENNIS D. MCCARTHY
U.S. Naval Observatory

LIEUTENANT LEE S. PUTNAM
U.S. Coast Guard Navigation Center

MR. JOHN R. RUSH
NASA Headquarters

MR. WILLIAM J. RYAN
Defense Information Systems Agency

DR. RICHARD L. SYDNOR
NASA Jet Propulsion Laboratory (Ret.)

MS. FRANCINE M. VANNICOLA
U.S. Naval Observatory

VACANT
Space and Naval Warfare Systems Command

VACANT
U.S. Air Force Space Command

MS. NICOLETTE M. JARDINE
Administrative Assistant
U.S. Naval Observatory

MS. CARMEN F. LÓPEZ
Administrative Assistant
U.S. Naval Research Laboratory

OFFICERS

General Chairman
MR. DONALD H. MITCHELL
TrueTime, Inc.

Technical Program Committee Chairman
DR. DENNIS D. MCCARTHY
U.S. Naval Observatory

TECHNICAL PROGRAM COMMITTEE
DR. HENRY F. FLIEGEL
The Aerospace Corporation

MR. PAUL F. KUHNLE
NASA Jet Propulsion Laboratory

DR. RICHARD L. SYDNOR
NASA Jet Propulsion Laboratory (Ret.)

MS. FRANCINE M. VANNICOLA
U.S. Naval Observatory

MR. S. CLARK WARDRIP
SFA, INC.

EDITORIAL COMMITTEE CHAIRMAN
DR. LEE A. BREAKIRON
U.S. Naval Observatory

TREASURER
DR. LEE A. BREAKIRON
U.S. Naval Observatory

EXHIBITS AND PUBLICITY COMMITTEE CHAIRMAN
MR. DONALD H. MITCHELL
TrueTime, Inc.

AUDIO-VISUAL CHAIRMAN
MR. PAUL F. KUHNLE
Jet Propulsion Laboratory

TECHNICAL ASSISTANCE
MR. JEFFREY S. INGOLD
AlliedSignal Technical Services Corporation

MEETING ARRANGEMENTS
MS. SHEILA FAULKNER
SFA, Inc.

DISTINGUISHED PTTI SERVICE AWARD COMMITTEE

DR. JOSEPH D. WHITE, CHAIRMAN
U.S. Naval Research Laboratory

DR. LEONARD S. CUTLER
Hewlett-Packard Company

DR. HENRY F. FLIEGEL
The Aerospace Corporation

DR. RICHARD L. SYDNOR
NASA Jet Propulsion Laboratory (Ret.)

PAST RECIPIENTS OF THE DISTINGUISHED PTTI SERVICE AWARD

1994
DR. GERNOT M. R. WINKLER
U.S. Naval Observatory
(Retired)

1995
DR. JAMES A. BARNES
National Institute of
Standards and Technology
(Retired)

1996
PROFESSOR SIGFRIDO M. LESCHIUTTA
Politenico di Torino and
Instituto Elettrotecnico Nazionale G. Ferraris

1997
PROFESSOR BERNARD R. GUINOT
Bureau International des Poids et Mesures
(Retired)

ADVISORY BOARD MEMBERS

MR. S. CLARK WARDRIP, CHAIRMAN
SFA, Inc.

Professor Carroll O. Alley
University of Maryland

Mr. Martin B. Bloch
Frequency Electronics, Inc.

Mr. Peter E. Cash
Frequency and Time Systems
Datum, Inc.

Mrs. Mary Chiu
The Johns Hopkins University
Applied Physics Laboratory

Lt. Col. Michael Cimafonte, USAF (Ret.)
System Technology Associates, Inc.

Dr. Leonard S. Cutler
Hewlett-Packard Company

Mrs. Sheila C. Faulkner
SFA, Inc.

Dr. Henry F. Fliegel
The Aerospace Corporation

Mr. Jeffrey S. Ingold
AlliedSignal Technical Services
Corporation

Mr. Robert H. Kern
KERNCO, Inc.

Dr. William J. Klepczynski
Innovative Solutions, Inc.

Dr. Paul A. Koppang
Sigma Tau Standards Group

Mr. Pete R. Lopez
TRAK Systems

Mr. Donald H. Mitchell
TrueTime, Inc.

Mr. Jerry R. Norton
The Johns Hopkins University
Applied Physics Laboratory

Mr. Allen W. Osborne, III
Allen Osborne Associates

Mr. Terry N. Osterdock
Absolute Time

Dr. Bradford W. Parkinson
Stanford University

Dr. Victor S. Reinhardt
Hughes Aircraft

Mr. William J. Riley
EG&G, Inc.

Dr. Harry Robinson
Duke University

Mr. Ronald C. Roloff
Advanced Technology Resources

Dr. Samuel R. Stein
Timing Solutions Corporation

Dr. Richard L. Sydnor
NASA Jet Propulsion Laboratory (Ret.)

Mr. Michael R. Tope
TrueTime, Inc.

Mr. James L. Wright
Computer Sciences Raytheon

SESSION CHAIRMEN

SESSION I

DR. EDWARD D. POWERS
U.S. Naval Observatory

SESSION II

MR. WILLIAM J. RYAN
Defense Information Systems Agency

SESSION III

DR. MARK A. WEISS
National Institute of
Standards and Technology

SESSION IV

MR. IVAN J. GALYSH
U.S. Naval Research Laboratory

SESSION V

DR. WLODZIMIERZ LEWANDOWSKI
Bureau International des
Poids et Mesures

SESSION VI

DR. GERARD PETIT
Bureau International des
Poids et Mesures

SESSION VII

DR. GERARD PETIT
Bureau International des
Poids et Mesures

SESSION VIII

DR. DIETER KIRCHNER
Technische Universität Graz

SESSION IX

MR. T. (JAY) JAYAWARENDA
AT&T Laboratories

SESSION X

DR. WILLIAM J. KLEPCZYNSKI
Innovative Solutions International

POSTER SESSION

MR. JEFFREY S. INGOLD
AlliedSignal Technical Services Corporation

ARRANGEMENTS

MRS. SHEILA FAULKNER
SFA, Inc.

MR. PAUL F. KUHNLE
NASA Jet Propulsion Laboratory

FINANCE COMMITTEE

MR. RONALD L. BEARD
U.S. Naval Research Laboratory

DR. JOSEPH D. WHITE
U.S. Naval Research Laboratory

DR. LEE A. BREAKIRON
U.S. Naval Observatory

THE RECEPTIONISTS AT THE 30TH ANNUAL PTTI MEETING WERE:

MS. NICOLETTE JARDINE
MRS. ALINE KUHNLE
MS. CARMEN LÓPEZ
MS. TERESA SMITH
MRS. BETTY WARDRIP

TABLE OF CONTENTS

SESSION II

NEW PRODUCTS FOR THE TIMING COMMUNITY

William J. Ryan, Chairman
Defense Information Systems Agency

Presentations were made by representatives of Absolute Time Corporation; Allen Osborne Associates, Inc.; Brandywine Communications; Datum, Inc.; Femtosecond Systems, Inc.; Navtech Seminars & GPS Supply; Quartzlock UK Ltd.; TeleComm Solutions/Symetracom; Temex, Inc.; 3S Navigation; TimeTech, GmbH; Timing Solutions Corporation; TRAK Microwave Corporation; TrueTime, Inc.; and WR, Inc.

SESSION III

ALGORITHMS AND ANALYSIS

Marc A. Weiss, Chairman
National Institute of Standards and Technology

POSTER SESSION

Jeffrey S. Ingold, Chairman
AlliedSignal Technical Services Corporation
(Papers have been reassigned to Sessions III, IV, VII, and IX)

SESSION IV

GPS/GLONASS I

Ivan J. Galysh, Chairman
U.S. Naval Research Laboratory

SESSION V

GPS/GLONASS II

Wlodzimierz Lewandowski, Chairman
Bureau International des Poids et Mesures

SESSION VI

APPLYING GPS CARRIER PHASE TO TIME AND FREQUENCY TRANSFER I

Gerard Petit, Chairman
Bureau International des Poids et Mesures

SESSION VII

APPLYING GPS CARRIER PHASE TO TIME AND FREQUENCY TRANSFER II

Gerard Petit, Chairman
Bureau International des Poids et Mesures

SESSION VIII

TWO-WAY SATELLITE TIME TRANSFER

Dieter Kirchner, Chairman
Technische Universität Graz

SESSION IX

FREQUENCY DISTRIBUTION

T. (Jay) Jayawardena, Chairman
AT&T Laboratories

SESSION X

NAVIGATION APPLICATIONS/GPS ENHANCEMENTS

William J. Klepczynski, Chairman
Innovative Solutions International

OPENING ADDRESS

Captain Dennis G. Larsen
Superintendent
U.S. Naval Observatory
Washington, DC

Good morning. I have a small book here of opening remarks that was prepared for me. I have been assured by my timing experts that it will take precisely ten minutes, which I think is the time allotted, assuming that I use the right frequency. I will try to keep on track here.

It is my pleasure to open the Thirtieth Annual Precise Time and Time Interval Meeting. The series, as most of you know, was started about 30 years ago to bring together the Department of Defense users of time with the experts to provide precise time and time interval. Since then, these PTTI meetings have expanded to include the international timing community and provide an opportunity for various users to bring forward their ideas and timing requirements for improving not only the Defense Department's needs, but also the needs of the world.

Similarly, these conferences have allowed time and time interval providers to make system developers aware of the latest improvements in the field. The objective of this series of meetings is mainly to disseminate and coordinate PTTI information at the user level; to review present and future PTTI requirements; to inform engineers, technicians, and managers of developing precise time and frequency technologies; and to provide an opportunity for an active dialog that is more important today than ever before.

In the past 30 years the accuracy with which time and time interval are measured and transferred has improved by three orders of magnitude, or an order of magnitude every decade. We have also witnessed remarkable growth in the use of time. It is safe to say that the development of precise time has played a critical role in the growth of technology that touches all of our lives today. The Global Positioning System is a prime example of a system based on timing that has had a remarkable impact on the world. There are many others.

Glancing at the program for this meeting, we will see that this year's schedule includes topics that promise even more significant developments for the future. Potential improvements in time and frequency standards provide a new challenge to develop timescale algorithms to steer the clocks of the next millennium. Our ability to transfer time is tested by the expected precision of these new standards, and significant improvements in time transfer will be required. A number of papers devoted to carrier-phase time transfer test this interest in the technique for improved time transfer.

All of these developments, however, bring on new issues that this meeting, and also future PTTI conferences, will have to address. The first concern that I would like to mention is the need to recognize operational standards for the timekeeping and time transfer. The Department of Defense and the U.S. has clearly recognized that inter-operability is a major issue. It has become evident that standards for time and time interval play an increasingly important role in assuring that modern systems can communicate among themselves and function effectively. We must strive to eliminate the costly practice of developing systems independently, without regard for the requirement to operate with other existing

and future systems. The application of advanced technology to address the world security needs demands that these systems adhere to standards in timing and in time transfer.

In 1998, Chairmen of the Joint Chiefs of Staff Master Position, Navigation, and Timing Plan and the Federal Radionavigation Plan assigned responsibility for DoD timekeeping to the U.S. Naval Observatory. We stand ready to assist those who are improving current systems and those who are developing new systems to eliminate needless and expensive duplication in the area of PTTI. One specific step the Naval Observatory is currently taking is hosting a meeting of the Naval Sea Systems Command-sponsored Timing and Synchronization Working Group, the Common Time Requirements System Engineering Team, or CTRSET, at the U.S. Naval Observatory on 12 January. This group is addressing the implementation of the common-time reference in the Navy and will eventually elevate this issue to the joint level. We will take that opportunity to hold a DoD PTTI meeting on the afternoon of the 12th to discuss future timing requirements for the Department of Defense.

A second issue being recognized at the CTRSET is that precise time is becoming a utility, much like that of electricity and communications. The ability to obtain precise time and time interval is assumed in the infrastructure of modern society. We often deal with users of precise time who are unaware of the dependence on availability of precise timing information. It is a product that most take for granted. Therefore, we must recognize the need to manage this new utility and meet society's current and future requirements.

Another interesting recognition came from the recent proposal by the GPS Independent Review Team for the GPS Joint Program Office to create a national GPtS – and that is a small "t." The initials stand for "Global Positioning and time System," with the "t" being small to show its fundamental importance. This management responsibility involves not only the productive stewardship of national resources, but also the recognition that a society makes increasing demands on time; we also make ourselves vulnerable to its disruption. National and international laboratories must work together to make sure that the world's timing needs are not compromised; requirements for redundant systems must also be evaluated carefully; and systems designers will have to deal with making provisions for adequate backups.

We who are in the business of providing time to users often complain how difficult it is to establish definitive requirements for time and time interval at these PTTI meetings. While we need to document requirements for budgetary purposes, users are often wary of being specific about their needs, feeling that they will be asked to fiscally support their timing demands. The need for documented requirements still exists, and I hope that this and future meetings will continue to address that need.

In addition, I would like to challenge users of time to think creatively about new possibilities that take advantage of our ability to provide time and time interval with much improved precision. Utility of precise time will in the future provide improvements to us all. We need to plan now to take advantage of this resource.

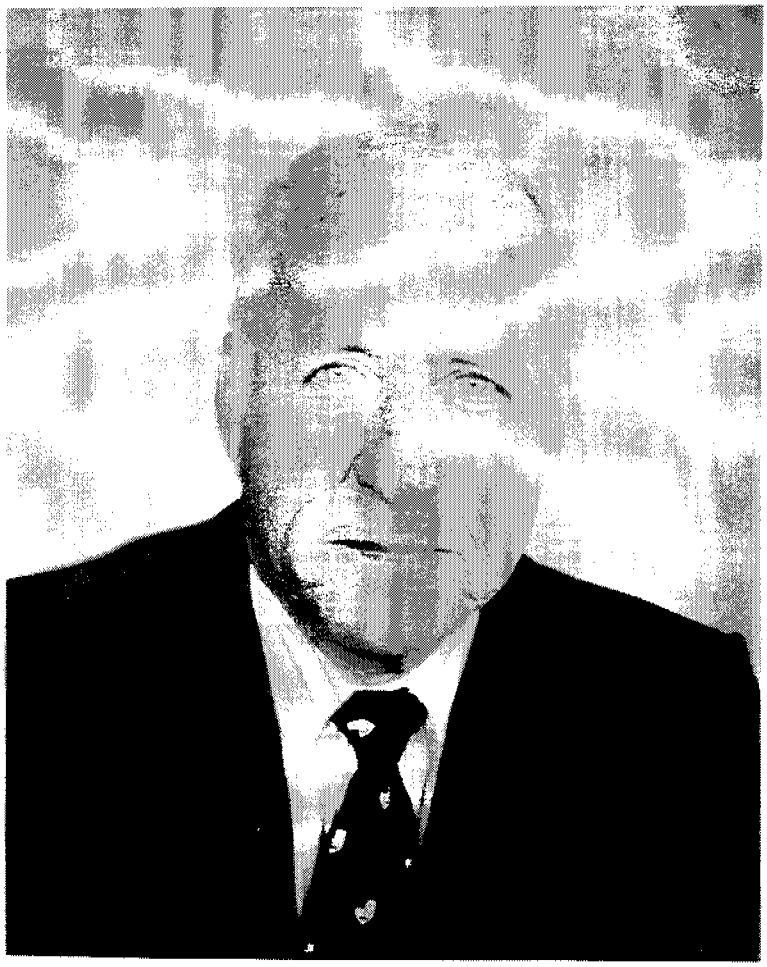
While we spend the next few days here discussing the latest developments in time and time transfer and innovative uses of timing. We also need to keep in mind these broader issues: standards for inter-operability, managing time as a national and international utility, PTTI vulnerabilities and backup systems, and creative planning for future utilization of precise timing.

I am looking forward to the presentations and discussions, and I thank you all for your attendance and for your participation. Thank you.

PTTI DISTINGUISHED SERVICE AWARD

Presented to
Dr. Jacques Vanier
Director General
Institute for National measurements Standards
National Research Council
Canada
(Retired)

by
Dr. Richard L. Sydnor
Jet Propulsion Laboratory
(Retired)



As you can see, I am not Leonard Cutler. Len had a recurrence of an illness and was hospitalized. He is doing well and is now home but could not make this trip. I am going to read what he has given us. The Distinguished Service Award Committee has selected Dr. Jacques Vanier from Canada this year.

Jacques Vanier was born in Canada. He received his B.A. and B.Sc. degrees in physics from the University of Montreal and his M.Sc. and Ph.D. in physics from McGill University, Montreal.

During his career Dr. Vanier has worked in various institutions, organizations and companies, such as University of Montreal, McGill University, Laval University, Defence Research Establishment, Varian Associates, Hewlett-Packard and the National Research Council of Canada. In this last institution, he was Director General of the Institute for National Measurement Standards. He is now Adjunct Professor of Physics at the University of Montreal. His teaching and research have been concentrated in solid state physics, semiconductors, thermodynamics, electromagnetism and quantum electronics. His most vivid souvenir of all his research activities is the day he dropped in the vacuum system of a hydrogen maser a cigar that a proud, new father had given him. To retrieve it, he had to take to pieces the whole system. This gave him solid experience to act as consultant for several companies such as Varian Associates, CA, Communication Components, CA, and EG&G, MA. He is now pursuing this activity for Kernco, MA. He also acted as Guest Worker in several organizations such as: the Centre National de la Recherche Scientifique (CNRS), France; the National institute of Standards and Technology (NIST), USA; the Instituto Elettrotecnico Nazionale (IEN) and the Universita di Pisa, Italy.

While pursuing these activities he could not resist being pulled into various committees and functions. Those he feels he may have made a contribution worth mentioning are: Union Radio Scientifique Internationale (URSI), President of Commission A (1990-1993); Conference of Precision Electromagnetic Measurements (CPEM), President of the 1990 Conference in Ottawa, and president of the Executive Committee (1990-1994); Frequency Standards and Metrology Symposium (initiator and co-founder); Administrative Committee of the I&M Society of the IEEE (1987-1993); Comité International des Poids et Mesures (1990-1996).

He is: Fellow of the Royal Society of Canada (RSC); Fellow of the American Physical Society (APS); and Fellow of the Institute of Electrical and Electronics Engineers (IEEE). In 1984, he received the IEEE Centennial Medal. In 1994, he was presented the Symposium on Frequency Control Rabi Award for his contributions to the field of atomic frequency standards.

He has written and published over ninety papers in scientific journals and conference proceedings. He spent six years in the writing of a book (with C. Audoin, Université de Paris as co-author): "The Quantum Physics of Atomic frequency Standards." To the question "Why that long?", his reply is, "With two authors it is twice as long."

Dr. Vanier is a dedicated painter. He presently pursues this activity and participates in various exhibitions. He uses oil as a medium and concentrates on Canadian landscapes. Dr. Vanier is also adept at boating. Confident in the usefulness of atomic clocks he has installed a Loran-C receiver in his boat. He says that the device can tell him accurately that the boat is in the Saint-Lawrence River and not on Saint-Catherine Street in downtown Montreal. He is thinking of switching to GPS.

Jacques, please come up to the podium, I would like to present you with the award. It is a clock.

Jacques Vanier

Thank you very much, Dick, for the kind words and for the humor contained in them.

I wish also to thank the committee which selected me for this award. In looking at this room and looking at the faces, I can see a lot of persons who deserve recognition in this field. I can only wish that one day they will experience the joy that I am enjoying at this moment in receiving this award.

Some time ago I decided to retire and do something else with my life. After an occasion like this one, I had questioned this decision. After a few years and after filling my house with paintings and creating the great collections of Vanier, in my house, I really questioned that. Then I received a timely invitation from Professor Leschiutta, from the IEN, to visit his institute and start doing something useful again. It did not take me long, maybe 50 microseconds in time interval, to make a decision. I am glad to say that I am back to quantum mechanics of atomic clocks again and trying to contribute. It was quite successful.

It is very exciting. Actually, I will say that it is a very privileged life. You do what you like most, and you get paid for it. Love this stuff, and people recognize you once in awhile. So, I would like to thank you again for this recognition. I feel that I belong to this group, and I find an identity in it. Thank you again very much.

30 YEARS OF PTTI – A RETROSPECTIVE

William J. Klepczynski
Innovative Solutions International
1608 Spring Hill Toad, Vienna, VA 22182
(202) 651-7670, *Bill.Klepczynski@faa.dot.gov*

Five years ago, my predecessor at the US Naval Observatory gave a history of PTTI which covered 25 years [1]. It is an excellent, informative and insightful review and I refer everyone to it. I do not think that you can find a better and more meaningful article.

This year I was asked to give a retrospective look at 30 years of PTTI. If you look up "retrospective" in a thesaurus, you will find a group of words which imply that a retrospective look of a subject is done from a personal point of view. These words include: looking back, contemplating the past, recollection, considering past events, remembering, perspective from the present, and memory. I will draw upon some of these different synonyms in this look based somewhat on personal experience. However, I will do it in a way which avoids mentioning the names of individuals, because, alas, I may miss a few and I do not wish to slight any of the people whom I might miss and for whom I have fond memories.

In the early 60's, I started at USNO in the Nautical Almanac Office. It was there that I became associated with the Institute of Navigation. This exposed me to the intrinsic and intimate relation of navigation with timing. It was with the ION that I first heard of Omega, Loran-C, TRANSIT, and vaguely something about 621B and Timation, the forerunners of GPS. It was an exciting experience because one could see the change that was rapidly taking place during that decade. In fact, the impact and role of navigation systems on timekeeping has been, is, and will continue to be dramatic. The land-based navigation systems that impacted timekeeping, such as Omega and Loran-C, gave way to GPS and now the role of GPS may be supplemented by the Satellite-Based Augmentation Systems currently being developed. These latter systems include the WAAS, EGNOS, and MSAS. They will enable global, real-time nanosecond synchronization to UTC.

On transferring to the Time Service Division in the early 70's, I immediately became involved with two entirely different aspects of practical timekeeping. The first being atomic time through participation in portable clock trips and the second being astronomical time through the construction of a 65 cm Photographic Zenith Tube (PZT) used in Earth Rotation studies. I believe portable clock trips led to the development of advanced time transfer techniques. There had to be an easier way to compare clocks than through the costly transport of 150 lb. behemoths. Also, for the first time I became aware of the National Bureau of Standards, now National Institute of Standards and Technology. During these last 30 years, both NIST and USNO have flourished. NIST developed its Cesium VII and USNO became the time reference for GPS.

While many here may not be aware of it, astronomy had played an important role in timekeeping during the early part of these last 3 decades. The definition of the second had just undergone great turmoil and change in the late 60's and early 70's. Relatively quickly, the basis of the SI second changed from the ephemeris second (astronomical) to the cesium second (atomic) and leap seconds were introduced into UTC.

Going back to astronomical time for the moment, the optical PZT was an instrument used to measure the rate of rotation of the Earth. It did this by comparing the time of transit of stars to time scales based on an ensemble of cesium clocks. While this instrument was productive over several decades, it became replaced by radio astronomy techniques. Such is the natural course of events. But the overall impact of astronomy in timekeeping was and is dwindling. UTC is no loner based on a purely astronomical measure. But, to this day, knowledge of Earth rotation for navigation is still extremely important. It is what limits the long-term, total, self-sufficiency of GPS. GPS needs to know how the Earth is rotating underneath it.

During the 70's, we saw the development of the improved cesium-beam tube (HP 5061, 004 option). This gave way to the HP 5071 cesium-beam frequency standard in the 80's. This was a very significant step in timekeeping. Also this era started to see the production of reliable hydrogen maser clocks. Now, masers are capable of running for extended periods of time without the need for a cast of thousands to keep them running. The role of the rubidium clock has more recently changed. Improvements in their design and construction have led to their choice in the next generation of GPS satellites.

The improvements in clock technology subsequently led to improvements in time scale calculation. A significant number of improvements in time scale algorithms included better weighting of clocks and the incorporation of different kinds of clocks into them. We are now seeing the development of time scale algorithms using Kalman filtering techniques, another significant milestone. Simultaneously with these improvements, there were significant advances in the characterization of the statistical behavior of clocks and the description their noise processes.

While portable clock trips were reaching their peak in the late 70's and the early 80's, alternative methods for time transfer were being developed and tested. The use of Omega and Loran-C gave way to GPS, probably the most significant factor affecting timekeeping during this period. It allowed global time transfer at the level of several nanoseconds. Experiments in two-way satellite time transfer using the ATS and Symphonie satellites led to the development of the Mitrex modem, which utilized PRN coded signals locked to the 1 PPS of a user's clock.

As my predecessor did at the end of his twenty-five year history of PTTI, I will also make some predictions for the future. However, mine may not be so conservative. In the not too distant future, it is entirely possible that UTC may yet undergo another revision and do away with the leap second. And, I already have mentioned the possibility of having a global, real-time synchronization capability at the 1 nanosecond level. Lastly, I see a possible restructuring of the major timing institutions in the United States.

I really feel blessed to have participated in this period of PTTI. There have been many advances and developments within a relatively short time span in which many of us at this meeting have taken part. We are in a unique field. It is composed of individuals who have developed an extraordinary sense of camaraderie. I am glad to have been a part of this exciting time in our history.

REFERENCES

[1] G. M. R. Winkler 1994, *"Twenty-five Years of PTTI,"* Proceedings of the 25th Annual Precise and Time Interval (PTTI) Applications and Planning Meeting, 29 November-2 December 1993, Marina del Rey, California, USA, NASA CP-3267, pp. 1-10.

Questions and Answers

DENNIS D. McCARTHY (USNO): Do you have any ideas on the redefinition of UTC?

WILLIAM KLEPCZYNSKI (ISI): What I see happening, where I work now, with the Satellite-based Augmentation System, many of the countries want to use existing systems, such as GPS and GLONASS. However, GLONASS has in its prime base UTC, which introduces the leap second. Whenever there is a leap second, GLONASS becomes unavailable for anywhere from two minutes to 20 hours. This last year there was a very significant outage because they also did a very big time step. To use it as the reliance on a safety-critical navigation system, I feel that it will not be accepted, that easily, until some change is made in the time basis. This may be one way to achieve that, or there might some momentum gathering for something like that.