

Proceedings of the Fifteenth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting

A meeting held at the
Naval Research Laboratory
Washington, D.C.
December 6-8, 1983

Sponsored by

Naval Observatory
NASA Goddard Space Flight Center
Naval Electronic Systems Command
Naval Research Laboratory
Defense Communications Agency
Chief of Naval Operations
National Bureau of Standards
Army Electronics Technology
and Devices Laboratory
Rome Air Development Center

EXECUTIVE COMMITTEE

Schuyler C. Wardrip, Chairman
NASA Goddard Space Flight Center

James A. Buisson
Naval Research Laboratory

Jimmie B. Collie
Naval Electronic Systems Command

Hugh S. Fosque
NASA Headquarters

Dr. William J. Klepczynski
Naval Observatory

Dr. Arthur O. McCoubrey
National Bureau of Standards

James A. Murray, Jr.
Naval Research Laboratory

Dr. Samuel R. Stein
National Bureau of Standards

Dr. Harris A. Stover
Defense Communications Agency

Dr. John R. Vig
Army Electronics Technology and Devices Laboratory

Dr. Gernot M. R. Winkler
Naval Observatory

Dr. Nicholas F. Yannoni
Rome Air Development Center

Sheila C. Faulkner
Naval Observatory
Administrative Assistant

GENERAL CHAIRMAN
Dr. Nicholas F. Yannoni
Rome Air Development Center

TECHNICAL PROGRAM COMMITTEE
CHAIRMAN
Dr. William J. Klepczynski
Naval Observatory

EDITORIAL COMMITTEE CHAIRMAN
L. J. Rueger
Johns Hopkins University/Applied Physics Laboratory

PUBLICITY CHAIRMAN
James A. Buisson
Naval Research Laboratory

SESSION CHARMEN

SESSION I

Advances in Time and Frequency Services

Dr. Derek Morris
National Research Council
Canada

SESSION II

GPS Time Transfer

Dr. Victor Reinhardt
Bendix Field Engineering Corporation

SESSION III

Time Transfer/Synchronization

Hugh S. Fosque
NASA Headquarters

SESSION IV

Mathematical and Statistical Techniques and
Their Applications to PTTI

Dr. James A. Barnes
Austron Inc.

SESSION V

PTTI Components

Dr. Arthur O. McCoubrey
National Bureau of Standards

SESSION VI

Classified Session

Dr. Gernot M. R. Winkler
Naval Observatory

ARRANGEMENTS

James A. Murray, Jr. NRL
Stella Scates, NRL
Susan Ramey, NRL

FINANCE COMMITTEE

James A. Buisson, NRL
S. Clark Wardrip, GSFC

PUBLICATIONS

Elaine Bowers, BFEC
L. J. Rueger, APL
S. Clark Wardrip, GSFC

NRL TECHNICAL ASSISTANCE

James Eng
Stanley Falvey
Alick Frank
Robert Hersh
Chester Kleczek
Mark Lister
Wayne Lloyd
Wade Root
Leighton Williams

PRINTING

Charles V. Hardesty, GSFC
Donald E. Ellis, GSFC

RECEPTIONISTS

Elaine Bowers, BFEC
Sheila Faulkner, USNO
Stella Scates, NRL
Betty Wardrip, GSFC

BANQUET SPEAKER

Robert E. Fischell, APL/JHU

SUBJECT: Time Controlled Release of
Medication By Implantable Devices

FOREWORD

These proceedings contain the papers presented at the Fifteenth Annual Precise Time and Time Interval Applications and Planning Meeting which was held December 6-8, 1983 at the Naval Research Laboratory. The discussions following the presentations are also included. There were 261 registered attendees, of which 31 were from 13 foreign countries.

The objective of the meeting was to provide an opportunity for program planners to meet those who are engaged in research and development and to keep abreast of the state-of-the-art and latest technological developments. At the same time, it provided an opportunity for the engineers and scientists to meet program planners. This objective is clearly reflected by the title of the meeting.

This year, the program emphasized advances in Time and Frequency Services of the various national laboratories, the use of the NAVSTAR Global Positioning Service for time transfer, and the mathematics and statistical techniques used in PTTI. Specialized PTTI applications and systems for Time Transfer/Synchronization and PTTI System Components were also included in the program. For the second time in the history of the PTTI meetings, a well-attended classified session was held.

The Executive Committee wishes to express its appreciation of the excellent work of the Session Chairman and the Technical Program Committee. The quality of the program remains excellent as is evidenced by the increasing registration and continuing support of our sponsors. The key to the success of a meeting such as this depends on the unstinting support of many volunteers. We are fortunate to have such support from the sponsors. In particular, the efforts of Messrs. S. Clark Wardrip and James Murray must be recognized, as well as the hospitality of the Naval Research Laboratory.

CONTENTS

	<u>Page</u>
CALL TO SESSION Dr. William J. Klepczynski	1
WELCOMING ADDRESS Jim Murray	3
OPENING COMMENTS Dr. William J. Klepczynski	5
SESSION I ADVANCES IN TIME AND FREQUENCY SERVICES	
Timing Accuracy of LF and TV Synchronization Techniques Miao Yun-rui and Pan Xiao-pei	9
New Time and Frequency Services at the National Bureau of Standards S. R. Stein, G. Kamas and D. W. Allan	17
Recent Improvements in the Atomic Time Scales of the National Bureau of Standards D. W. Allan, D. J. Glaze, J. E. Gray, R. H. Jones, J. Levine, and S. R. Stein	29
Automation of Precise Time Reference Stations (PTRS) Paul J. Wheeler	41
U.S. Naval Observatory Collection and Utilization of Time Comparison Data F. Neville Withington	53
International Time Comparison by a GPS Timing Receiver M.-K. Fujimoto, K. Fujiwara, and S. Aoki	71
SESSION II GPS TIME TRANSFER	
First Results of GPS Time Transfer to Australia John McK. Luck, John R. Woodger, James E. Wells, Peter N. Churchill and Philip A. Clements	87
Separating the Variances of Noise Components in the Global Positioning System David W. Allan and Marc Weiss	115
Enhancements to the TTS-502 Time Transfer System Dr. A. J. Van Dierendonck and Dr. Q. D. Hua	133

CONTENTS (continued)

	<u>Page</u>
A New Precision Time and Frequency Source for Stationary PTTI Applications	155
Javad M. Ashjaee, Roger J. Helkey and Ron C. Hyatt	
On-Orbit Frequency Stability Analysis of the GPS NAVSTAR's 3 and 4 Rubidium Clocks and NAVSTAR's 5 and 6 Cesium Clocks	171
Thomas B. McCaskill, James A. Buisson and Sarah B. Stebbins	
GPS Navigation Experiment Using High Precision GPS Timing Receivers . . .	211
J. Buisson, O. J. Oaks, M. Lister, S. C. Wardrip, S. Leschiutta, P. G. Galliano, F. Cordara, V. Pettiti, E. Detoma, P. Dachel, H. Warren, T. Stalder, F. Fedele and R. Azzarone	
Improved Master Clock Reference System at USNO	237
Gernot M. R. Winkler	
The Steering of GPS Time	249
H. F. Fliegel	
Test Results for Prototype GPS Rubidium Clocks	269
T. J. Lynch and W. J. Riley	

SESSION III TIME TRANSFER/SYNCHRONIZATION

International Time Transfer and Portable Clock Evaluation Using GPS Timing Receivers: Preliminary Results	283
S. C. Wardrip, J. Buisson, O. J. Oaks, M. Lister, E. Detoma, P. Dachel, T. Stalder, H. Warren, G. Winkler, G. Luther, S. Leschiutta, P. G. Galliano, F. Cordara, V. Pettiti, R. Azzarone and F. Fedele	
Spread Spectrum Time Transfer Experiment Via INTELSAT	331
Dr. P. Hartl, L. Veenstra, N. Gieschen, K.-M. Mussener, W. Schafer, C.-M. Wende, Dr. W. Klepczynski, H.-H. Nau and R. Stoiber	
Unattended TV Time Transfer Results	357
John A. Waak and John H. Spencer	
The Role of a Low Earth Orbiter in Intercontinental Time Synchronization Via GPS Satellites	371
Sien-Chong Wu and V. John Ondrasik	
Timing of Spacecraft Data	389
H. P. Dworak	

CONTENTS (continued)

	<u>Page</u>
UHF IRIG G Distribution System M. Tope	413
Timing System Design Considerations for a Mobile Astrolabe Carl F. Lukac, Paul J. Wheeler, Richard E. Keating, and Randolph T. Clarke	423
Precise Time Transfer Using MKIII VLBI Technology K. J. Johnston, J. A. Buisson, M. J. Lister, O. J. Oaks, J. H. Spencer, W. B. Waltman, G. Elgered, G. Lundqvist, A. E. E. Rogers, T. A. Clark, C. Ma, A. C. Johnson, K. Kingham, W. J. Klepczynski, G. Luther, A. J. Kubic, and D. D. McCarthy	443
SESSION IV MATHEMATICAL AND STATISTICAL TECHNIQUES AND THEIR APPLICATION TO PTTI	
Clock Characterization Tutorial David W. Allan	459
Methods for Optimal Recursive Estimation of Non-Stationary Time Series, Applications to Atomic Time and Frequency Metrology Z. Y. Weng, J. Rutman and J. Uebersfeld	477
Applied Kalman Filtering: An Overview R. Grover Brown	503
Kalman Filtering with a Two-State Clock Model Fran B. Varnum	519
Kalman Filter Estimates of the NAVSTAR Satellite Clock Parameters Paul S. Jorgensen	531
The Measurement of Linear Frequency Drift in Oscillators James A. Barnes	551
A Plan for the Development of Inertial Reconstruction of Initial State Clock (IRIS) Ernest G. Kimme, Ph.D.	583
SESSION V PTTI COMPONENTS	
High Performances from a New Design of Crystal Oscillator G. Beauvy, G. Marotel and P. Renault	621
Design of SC Cut 10 MHz H.Q. Crystals with G. Sensitivity Better than $2.10^{-10}/G$ A. Debaisieux, J. P. Aubry and J. Groslambert	635

CONTENTS (continued)

	<u>Page</u>
Recent Results on the Performance of EFOS, NP and NX Hydrogen Masers	653
V. Reinhardt, J. Ingold, T. Stalder, M. Saifi, P. Dachel and S. C. Wardrip	
Physics Element Design Aspects for a Tactical Rubidium Frequency Standard . .	677
Bruce Grover and Tae M. Kwon	
Crystal Resonator/Oscillator Test Facility and Test Results.	693
V. J. Rosati and R. L. Filler	
Time Synchronization Experiments with Apple.	707
C. L. Jain, K. Kumar, M. R. Sivaraman, B. S. Mathur, P. Banerjee, A. Sengupta, Mithlesh Saxana, A. K. Hanjura and A. K. Suri	
The Superconducting Cavity Stabilized Ruby Maser Oscillator.	723
G. J. Dick and D. M. Strayer	
CLOSING REMARKS. .	741

CALL TO SESSION

Dr. William J. Klepczynski
Program Chairman
United States Naval Observatory

DR. KLEPCZYNSKI: My name is Bill Klepczynski, and I am the program chairman for this meeting. Unfortunately, the general chairman of the meeting, Dr. Nicholas Yannoni, is ill and could not, therefore, make it for today. So, on his behalf, I would like to extend to you a hearty welcome for your attendance here at the Fifteenth Annual P.T.T.I. Meeting.

Authors of papers, Lauren Rueger, who is here, I'll ask him to stand up, he is to receive your paper sometime, during the three days of the meeting, for publication in the Proceedings of the Fifteenth Annual Precision Time and Time Interval Planning Conference.

For our welcoming address I would like to introduce Jim Murray of the Naval Research Laboratory.

WELCOMING ADDRESS

Jim Murray
Naval Research Laboratory

MR. MURRAY: I am sorry that our Commanding Officer, Captain McMorris, will not be able to be here for the welcoming address; but, on his behalf, I would like to extend to you a wish for a very successful meeting.

The laboratory is not new to this meeting. We have been associated with it for the past fifteen years, back to when it first started. During that time we have seen the number of sponsors increase by an order of magnitude; from one to ten, and we have seen the nanosecond replace the microsecond as the most talked about unit of time; and now we can even use picoseconds without a footnote. These are all signs of progress, and these are things that the timing community has done; but there's another sign of progress, and that's the growing number of users that describe their systems in terms of these units. For this, our meetings can take proper credit.

We are responsible for letting the potential users know what has been done, what is being done, and what is planned in timing. In this way, we have helped them to take advantage of the kinds of precise timing that can improve their systems.

P.T.T.I. meetings have been very successful in accomplishing their purposes, and I am sure this meeting will enjoy the same productivity as those in the past.

We have many foreign visitors here and we are very happy to have them. We are sorry for the inconvenience that our entry procedures have caused, but this is just part of our system that we cannot do without.

I welcome you here and I wish you success in your meeting.

OPENING COMMENTS

Dr. William J. Klepczynski
Technical Program Committee
United States Naval Observatory

DR. KLEPCZYNSKI: I would like to talk about the program very briefly. As Jim mentioned, today microsecond timing is available throughout most of the world; and in some instances, we have nanosecond timing. This has really taken place in the last fifteen or sixteen years. I think the first Hewlett-Packard cesium box came out about 1967 or '68, and ever since that time the timing community and users of precise time have made quantum leaps in their systems; and the programs reflect some of these advances.

The first session we have is devoted to advances in the services provided by the various national laboratories.

We have another session on C.P.S. time transfer; one of the most up-to-date systems, which will assure nanosecond timing throughout the world.

One session is devoted to the mathematics of precision time and frequency. Since we have not dealt with that for a long time, we thought some interesting tutorials would be worthwhile for the people who attend the meetings.

There is one classified session which will not be held in this auditorium; it will be held in a separate building and is restricted to cleared U.S. citizens. So please take this into consideration.

If you have a question would you identify yourself, because the sessions are being recorded for the proceedings of the conference, and we can then get your name and affiliation as well as your words.

With that, I would like to introduce the chairman of the first session, Dr. Derek Morris, National Research Council of Canada.