

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

**A meeting held at the
DuPont Plaza Hotel
Washington, D.C.
December 2-4, 1986**

Sponsored by

**Naval Observatory
NASA Goddard Space Flight Center
Space and Naval Warfare Systems Command
Naval Research Laboratory
National Bureau of Standards
Army Electronics Technology
and Devices Laboratory
Rome Air Development Center
USAF Space Command**

EXECUTIVE COMMITTEE

Sheila C. Faulkner, Chairman
U.S. Naval Observatory

David W. Allan
National Bureau of Standards

James A. Buisson
U.S. Naval Research Laboratory

Jimmie B. Collie
Space and Naval Warfare Center

Hugh S. Fosque
NASA headquarters

Dr. William J. Klepczynski
U.S. Naval Observatory

Straton C. Laios
NASA Goddard Space Flight Center

Dr. Arthur O. McCoubrey
National Bureau of Standards

Dr. John R. Vig
U.S. Army Electronics and Devices Laboratory

Dr. H. Beat Wackernagel
U.S. Air Force Space Command

Dr. Joseph White
U.S. Naval Research Laboratory

Dr. Gernot Winkler
U.S. Naval Observatory

Dr. Nicholas F. Yannoni
Rome Air Development Center

GENERAL CHAIRMAN

DR. JOSEPH WHITE

U.S. Naval Research Laboratory

TECHNICAL PROGRAM COMMITTEE CHAIRMAN

ROBERT H. KERN

Kernco, Inc.

EDITORIAL COMMITTEE CHAIRMAN

DR. RICHARD L. SYDNOR

Jet Propulsion Laboratory

PUBLICITY CHAIRMAN

JIMMIE B. COLLIE

Space and Naval Warfare Systems Command

SESSION CHAIRMEN

SESSION I

Dr. John R. Vig

U.S. Army Electronics Technology
and Devices Laboratory

SESSION II

Dr. Bernard Guinot

Bureau International de l'Heure

SESSION III

James A. Buisson

U.S. Naval Research Laboratory

SESSION IV

Ms. Laura Charron

U.S. Naval Observatory

SESSION V

Dr. Miles Missout

Institut de recherche d'Hydro-Quebec

SESSION VI

Dr. Nicholas F. Yannoni

Rome Air Development Center

ARRANGEMENTS

**Sheila C. Faulkner
Paul Kushmeider**

FINANCE COMMITTEE

**James A. Buisson
James A. Murray, Jr.**

RECEPTIONISTS

**Elaine Bowers, Bendix
Frances Knight, NRL
Bettejean McKnight, NRL
Earle Noble, Naval Observatory
Sally Plumb, Naval Observatory
Betty Wardrip, Bendix**

PTTI ADVISORY BOARD MEMBERS

FEBRUARY 1987

Members and officers of the Advisory Board will be selected every second and third year (for a three year term) starting in January 1988 and January 1989 respectively, after the initial two and three year terms, so as to have a one or two year overlap of membership. In other words, there will be selections of half the members in January 1988/89, January 1991/92, January 1994/95, etc. The following members were selected in 1986 for the terms indicated. Future members will be selected by the Advisory Board and will serve with the approval of the PTTI Executive Committee. It is possible for a member, if selected, to serve for more than one term.

<u>OFFICE</u>	<u>TERM</u>	<u>NAME</u>	<u>ORGANIZATION</u>
Chairman	3 yrs.	Mr. S. Clark Wardrip	BFEC
Vice Chariman	3 yrs.	Mr. Martin B. Bloch	FEI
Finance Committee	3 yrs.	Mr. Martin B. Bloch, Chariman	FEI
	2 yrs.	Mr. Robert H. Kern	KERNCO
	2 yrs.	Mr. Frank Koide	SAIC
	3 yrs.	Mr. Frank Matthews	FEC/WTR
	3 yrs.	Mr. James L. Wright	PanAm/WTR
Exhibits Committee	3 yrs.	Dr. James A. Barnes, Chariman	Austron
	2 yrs.	Dr. Martin Levine	FTS
	2 yrs.	Mr. William J. Riley	EG&G
	3 yrs.	Dr. Robert F. C. Vessot	SAO
	3 yrs.	Mr. Jeffrey W. McDonald	Truetime
Guest Speaker Committee	3 yrs.	Dr. Leonard S. Cutler, Chairman	HP
	2 yrs.	Professor Carroll O. Alley	Univ. of Md.
	3 yrs.	Dr. Victor S. Reinhardt	Hughes
	2 yrs.	Dr. Samuel R. Stein	Ball/Efratom
	2 yrs.	Dr. Richard L. Sydnor	JPL
Reports Committee	3 yrs.	Mr. Lauren J. Rueger, Chairman	APL
	2 yrs.	Mr. Terry N. Osterdock	STI
	3 yrs.	Dr. Harry Robinson	Duke Univ.
	2 yrs.	Mr. Philip E. Talley	Aerospace
	3 yrs.	Mr. S. Clark Wardrip	BFEC

PTTI ADVISORY BOARD MEMBERS

FEBRUARY 1987 (CONT.)

<u>OFFICE</u>	<u>TERM</u>	<u>NAME</u>	<u>ORGANIZATION</u>
1987 PTTI Officers		Mr. Robert H. Kern PTTI General Chairman	KERNCO
		Dr. Bradford W. Parkinson PTTI Program Chairman	Stanford
		Dr. Richard L. Sydnor PTTI Editorial Chairman	JPL

NOTE: NON-GOVERNMENT OFFICERS OF THE PTTI ARE AUTOMATICALLY MEMBERS OF THE PTTI ADVISORY BOARD FOR THE YEAR(s) THAT THEY ARE IN OFFICE.

1987 PTTI ADVISORY BOARD MEMBERSHIP

ADDRESS/TELEPHONE LIST

Professor Carroll O. Alley
University of Maryland
Department of Physics and Astronomy
College Park, Maryland 20742
301/454-3405

Dr. James A. Barnes
Austron, Inc.
3300 Mitchel Lane
Boulder, Colorado 80301
303/440-7282

Mr. Martin B. Bloch
Frequency Electronics, Inc.
55 Charles Lindbergh Boulevard
Uniondale, New York 11553
516/794-4500

Dr. Leonard S. Cutler
Hewlett-Packard Company
1651 Page Mill Road
Palo Alto, California 94304
415/857-5259

Dr. Martin Levine
Frequency and Time Systems, Inc.
34 Tozer Road
Beverly, Massachusetts 01915
617/927-8220

Mr. Robert H. Kern
Kernco, Inc.
28 Harbor Street
Danvers, Massachusetts 01923-0678
617/777-1956

Mr. Frank Koide
Science Applications International
Corp.
3456 Camino del Rio North
San Diego, California 92108
619/283-5492

Mr. Frank Matthews
ITT Federal Electric Corp.
P.O. Box 5728
Code OE600
Vandenberg Air Force Base,
California, 93437
805/866-7590

Mr. Jeffrey W. McDonald
Kinematics/Truetime
3243 Santa Rosa Avenue
Santa Rosa, California 95407
707/528-1230

Mr. Terry N. Osterdock
Stanford Telecommunications, Inc.
2421 Mission College Boulevard
Santa Clara, California 95054
408/982-5903

Dr. Bradford W. Parkinson
Stanford University
Hansen Labs, Via Palou
Stanford, California 94305-4085
415/725-4107

Dr. Victor S. Reinhardt
Hughes Aircraft
Space and Communications
S12/W322, P.O. Box 92919
Los Angeles, California 90009
213/416-0160

Mr. William J. Riley
EG&G, Inc.
35 Congress Street
Salem, Massachusetts 01775
617/745-3200

Dr. Harry Robinson
Duke University
Department of Physics
Durham, North Carolina 27706
919/684-8226

Mr. Lauren J. Rueger
Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, Maryland 20707
301/953-5288

Dr. Samuel R. Stein
Ball Efratom Division
P.O. Box 589
Broomfield, Colorado 80020
303/460-5227

1987 PTTI ADVISORY BOARD MEMBERSHIP

ADDRESS/TELEPHONE LIST (Cont.)

Dr. Richard L. Sydnor
Jet Propulsion Laboratory
4800 Oak Grove Drive
M/S 298
Pasadena, California 90803
818/354-2763

Mr. Philip E. Talley
The Aerospace Corporation
550 Margo Avenue
Long Beach, California 90803
213/336-7597

Dr. Robert F. C. Vessot
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 01945
617/495-7272

Mr. S. Clark Wardrip
Bendix Field Engineering Corporation
P.O. Box 6147
Vandenberg Air Force Base,
California 93437
805/865-3888

Mr. James L. Wright
Pan American World Airways
Eastern Test Range
Building 989, MU 840
Patrick Air Force, Florida 32925
305/494-2014

OPENING REMARKS

ROBERT H. KERN

Technical Program Chairman

Good Morning. I want to welcome you to the 18th Annual PTTI Meeting and to wish you much success in your attendance at these sessions. We have three busy days ahead of us with the serial presentation of some 47 papers and reports.

The theme of this year's meeting was the promotion of closer government and industry cooperation in the PTTI planning and technology exchange functions. A significant advance toward this objective occurred with the creation of the industrially based PTTI Advisory Board with S. Clark Wardrip as its first chairman. I suspect that Clark will have some things to say about his first board experiences at the PTTI banquet on Wednesday night.

As has been mentioned earlier, I recommend that you get your tickets today because of limited space available for what promises to be one of our better banquets.

Today's sessions are specifically intended to bring us first-hand reports of the roles which the PTTI laboratories play in the planning, control and, hopefully, advancement of PTTI activities. We then follow up on Wednesday and Thursday with five more sessions which will report on specific applications of the PTTI art.

Dr. John Vig of the U.S. Army Electronics Technology and Devices Laboratory will begin our meeting by chairing the first session on PTTI Programs and Planning. John needs no introduction. I would ask you to accord John and all of our session chairs the courtesy of announcing your name and your affiliation into a microphone when questions are invited. The meeting is being recorded and our Editorial Chairman, Dick Sydnor, will utilize the tapes to produce accurate proceedings.

CONTENTS

SESSION 1

PTTI, PROGRAMS AND PLANNING

Chairman: Dr. John R. Vig
U.S. Army Electronics Technology and Devices Laboratory

Activities and plans of the Time and Frequency Division of the National Bureau of Standards	1
D. Sullivan, National Bureau of Standards	
Atomic Clock Research in the Aerospace Corporation Chemistry and Physics Laboratory-An Overview	11
N.D. Bhaskar, J.C. Camparo, B. Jaduszliwer, and C.M. Klimcak, The Aerospace Corporation	
GPS Clock Technology and Navy PTTI Programs at the U.S. Naval Research Laboratory	37
R.L. Beard, J. Murray and J.D. White, Naval Research Laboratory	
Precision Time and Frequency Sources and Systems Research and Development at the Johns Hopkins University Applied Physics Laboratory	55
A.G. Bates, M.C. Chiu and J.J. Suter, The Johns Hopkins University Applied Physics Laboratory	
Frequency Standards Work and Timekeeping at the National Research Council of Canada	71
J.S. Boulanger, C.C. Costain, R.J. Douglas, C. Jacques, D. Morris, P. Tremblay and J. Vanier, National Research Council of Canada	
U.S. Army PTTI/Frequency Control Activities and Plans	79
J.R. Vig, U.S. Army Electronics Technology and Devices Laboratory	
A Review of the Frequency and Timing Activities at the Jet Propulsion Laboratory	89
L. Maleki and P. Kuhnle, Jet Propulsion Laboratory	

SESSION II

INTERNATIONAL TIMEKEEPING/PTTI

Chairman: Dr. B. Guinot
Bureau International de l'Heure

BIH Report	99
Dr. D. Guinot, Bureau International de l'Heure	
Time-Related Activities at the Royal Greenwich Observatory	109
J.D.H. Pilkington, Royal Greenwich Observatory	
National Physics Laboratory, U.K. Time and Frequency Report, 1986	113
P.B. Coates, J.E. Gibbs, D.J.E. Knight, D.S. Sutcliffe and B.R. Swabey, National Physics Laboratory	
Timekeeping and Time and Frequency Dissemination at the Istituto Elettrotecnico Nazionale (I.E.N.)	131
F. Cordara and V. Pettiti, Istituto Elettrotecnico Nazionale	
A New Principle of Linear Phase Comparison- Irregular Phase Discrimination	149
Zhou Wei, Shaanxi Institute for Measurement and Testing	
Activities on Time and Frequency at the Shanghai Observatory	155
Zhai Zaocheng, Zhuang Qixiang, Hu Jinlin and Kiu Wunwei, Shanghai Observatory	
Research Activities on Time and Frequency at Radio Research Laboratory	165
N. Imai, S. Kobayashi, K. Yoshimura, and K. Nakagiri, Radio Research Laboratory Ministry of Posts and Telecommunications	
Status of Activities and Plans for Precise Time Comparisons in Australia	177
R. Harris, G. Harvey and J. Luck, National Standards Communications Division of National Mapping	
A Phase Comparison Method Suitable to Measure H-Maser Performance	195
Dr. R. Ambrosini, Consiglio Nazionale Delle Ricerche Istituto Di Radioastronomia	
Use of LF and VLF Radio Frequency Calibration in Egypt	203
Dr. Safaa Samuel, National Institute for Standards	

SESSION III

GPS TIME/TIME TRANSFER

Chairman: J. Buisson
U.S. Naval Research Laboratory

Navstar GPS Program Status and Phase III	
Gps User Equipment	213
LCDR Per Wilhelm Nieuwejaar, Space Division, U.S. Air Force	
Rubidium and Cesium Frequency Standards Status and Performance on the GPS Program	227
M.J. Van Melle, Rockwell International	
GPS Time Steering	237
W.J. Klepczynski, U.S. Naval Observatory; H.F. Fliegel, The Aerospace Corporation; D.W. Allan, National Bureau of Standards	
Various Uses of the OCS Tracking Data	251
P.S. Jorgensen, The Aerospace Corporation	
A Calibration of GPS Equipment at Timing Laboratories in Europe	265
M.A. Weiss, National Bureau of Standards; Wlodzimierz Lewandowski, Bureau International de l'Heure	
Remote Clock Calibration Via GPS	283
G.H. Luther, L.G. Charron and R.E. Keating, U.S. Naval Observatory	
WSMC Approach for Using GPS to Synchronize Remote Site Timing	295
J.B. McConnell, Western Space and Missile Center; R.L. Baker, ITT-Federal Electric Corporation	
Precise Time from GPS for Department of Defense Test and Training Ranges	305
J.D. Luse and S.S. Sanford, Interstate Electronics Corporation	
A New Technique for the On-Orbit Characterization of Cesium Beam Tube Performance	321
S.K. Karuza, J.P. Hurrell and W.A. Johnson, The Aerospace Corporation	

SESSION IV

PTTI USER REPORTS

Chairman: MS. Laura Charron
U.S. Naval Observatory

Timing Calibration of the Northeast U.S.A. Loran-C Chain (9960)	331
R.E. Keating, C.F. Lukac, G.H. Luther and L.G. Charron, U.S. Naval Observatory	
Civil Access to the Precise Positioning Service of the Navstar Global Positioning System	353
M.J. Ellett, Navstar GPS Joint Program Office	
The Synchronization and Syntonization of Molecular (Biological) Clock Ensembles	363
S. Ward, Jet Propulsion Laboratory	
Reference Frequency Transmission Over Optical Fibers	385
G. Lutes and A. Kirk, Jet Propulsion Laboratory	
Results of Using the Global Positioning System to Maintain the Time and Frequency Synchronization in NASA's Jet Propulsion Laboratory's Deep Space Network	395
P.A. Clements, A. Kirk and R. Unglaub, Jet Propulsion Laboratory	
GPS-Based Network Syntonization Via Nonmagnetic Control of Cesium Standards	407
E.A. Rodrigo, J. Howell, J. Barnes and J.D. Echols, Austron Corporation	
Assessing the Validity of Suboptimal 2-State Clock Models	421
In Soo Ahn and R. Brown, Iowa State University	
Stability Measurements of Ku-Band Spread Spectrum Two-Way Time Transfer Equipment	427
D.A. Howe, National Bureau of Standards	
Millisecond Pulsar Rivals Best Atomic Clock Stability	453
L. Rawley, D. Stinebring, and J. Taylor, Princeton University; M. Davis, Arecibo Observatory and D.W. Allan, National Bureau of Standards	

SESSION V

PTTI APPLICATIONS

Chairman: Dr. Giles Missout
Institut de recherche d'Hydro-Québec

Timing Within the Western Area Power Administration	467
R. E. Wilson, Western Area Power Administration	
PTTI Applications in Power Utilities	491
Dr. Giles Missout, Institut de recherche d'Hydro-Québec	
Beam Optics of RRL Cesium Beam Primary Frequency Standard	503
K. Nakagiri, H. Okazawa and S. Urabe, Radio Research Laboratory	
Absolute Time Synchronization Between Power System Fault Recorders and Sequence of Events Recorders	515
R. O. Burnett, Jr., Georgia Power Company	
PTTI Systems on the Eastern Test Range	529
James L. Wright, Pan Am Word Services, Inc.	
A Telephone-Based Time Dissemination System	541
D. Jackson, Leitch Video International; R. Douglas, National Research Council of Canada	
Precise Time Transfer Using the Starfix™ System	555
A. R. Dennis, Analytical Technology Laboratories	

SESSION VI

PTTI TECHNOLOGY

Chairman: Dr. Nicholas Yannoni
Rome Air Development Center

Frequency Stability in a Wall-Coated Evacuated Cell	559
C. Rahman and H. G. Robinson, Duke University	
A Partial Analysis of Drift in the Rubidium Gas Cell Frequency Standard	565
J. C. Camparo, The Aerospace Corporation	

An Environmentally Hardened Precision Quartz Oscillator	589
S. Bass, B. T. Milliren and R. M. Garvey, Frequency and Time Systems, Incorporated	
The Superconducting Cavity Maser Oscillator- Toward Higher Stability	601
D. M. Strayer and G. J. Dick, Jet Propulsion Laboratory	
A Subcompact Q-Enhanced Active Hydrogen Maser	611
R. R. Hayes and H. T. M. Wang, Hughes Research Laboratories	
A Signal Processing Scheme for Reducing the Cavity Pulling Factor in Passive Hydrogen Masers	621
K. M. Uglow, Electronics Research	
Integral Cavity Hydrogen Maser	631
R. Kanski, The Johns Hopkins University	