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FOREWORD

These proceedings contain the papers presented at the Twelfth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting held December 2-4, 1980, at NASA Goddard Space Flight Center. They also include the discussions following the presentations.

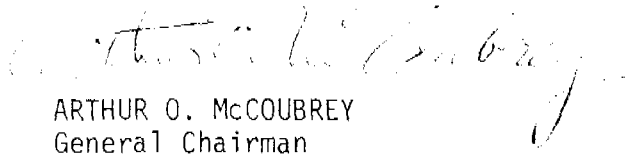
The purpose of the PTTI Applications and Planning Meeting, as defined for 1980, was to give Managers, Systems Engineers, Program Planners, and Industry:

- An opportunity to discuss current and future needs, problems, and programs;
- An overview of state-of-the-art in PTTI applications;
- A review of significant accomplishments in applications;
- A view of important future trends;
- Future applications.

There were 220 registered attendees from government, private industry, universities, and 19 registrants came from foreign countries.

This year, a special emphasis was placed upon the subject of reliability, which has become critically important in the applications of PTTI equipment. With this in mind, speakers were invited to describe their experiences in achieving high levels of reliability in other programs involving high technologies. In addition, the technical program was organized in order to emphasize the importance of views of industry, on one hand, and the views of government officials, on the other hand, in the process of effective planning.

On behalf of the Executive Committee, I particularly want to recognize the excellent efforts of the Session Chairmen and of the Technical Program Committee under the leadership of Mr. C. A. Bartholomew. As in the past, the quality of the technical program was excellent, and the interest in PTTI continues at a high level. I also want to thank the Session Chairmen for their efficient conduct of the Meeting. Finally, it is a pleasure to recognize the contributions of S. Clark Wardrip and the hospitality of NASA Goddard Space Flight Center.



ARTHUR O. McCOUBREY
General Chairman

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CALL TO SESSION

Dr. Arthur O. McCoubrey
National Bureau of Standards

DR. MCCOUBREY: Good Morning. As your General Chairman, it is my pleasure to call to order this 12th Annual Precise Time and Time Interval Applications meeting. I am very pleased to note that the interest in this meeting remains high and that the attendance is already excellent.

Let me remind you of the purpose of the PTTI meeting. It is a meeting to provide managers, system engineers, program directors, and industry with an opportunity to discuss, for planning purposes, current and future needs, problems and programs, to provide for an overview of the state-of-the-art in PTTI applications, to review significant accomplishments in applications, and to review important future trends in applications. I am pleased to say that we have an excellent technical program. The technical interest in this Precise Time and Time Interval Applications meeting remains very high reflecting the rapid advances that continue to emerge.

I want to thank the Technical Program Committee, ably headed by Mr. Charles Bartholomew. They have selected 47 papers from those submitted. Forty-one of these papers will be included in the formal program and a number of additional papers which cannot be included in the formal presentations because of time limitations will be published in the proceedings. Forty-one papers in the formal program exceeds the number presented last year, and I am sure you will appreciate that we have a crowded schedule.

The emphasis which we have selected today for the opening session of the meeting places the subject of reliability up front. PTTI is a field in which applications of very advanced technology are necessary and I am sure you will agree that the questions of reliability is not only important now, but as we apply this technology in more and more demanding situations the importance continues to increase. Therefore, the first session this morning brings a number of speakers from fields in which reliability has been an essential objective for many years; we will have the benefit of their important experience in advanced technology field other than PTTI.

Later today, during this afternoon, the first part of Session II will deal with the perceptions of Government planners; this part of the meeting will be moderated by industry. Later in the afternoon, the second part of the planning session takes up the industry views; this part will be moderated by Government representatives.

Tomorrow we have a session on time transfer. We also have a session on frequency standards and clocks. On Thursday a session on advanced technology is scheduled.

Let me remind you that, as usual, on Wednesday evening we have our informal banquet. This year we are very privileged to have Professor Joseph Webber as a speaker. Professor Webber divides his time between the University of California at Irvine and the University of Maryland here in College Park. His subject tomorrow evening is Listening for Extra Terrestial Intelligence. Professor Webber is a most interesting speaker and we will have a very interesting evening. I urge you to attend and, in this connection, I also urge you to make your plans early and purchase your tickets.

Next then it is a pleasure for me to call upon officials of our sponsoring agencies to open the meeting. First let me call upon a represena-time of our host institution, NASA Goddard Space Flight Center. NASA Goddard is also a sponsor of PTTI and it is a pleasure for me to introduce Dr. John McElroy, Deputy Director of NASA Goddard Space Flight Center.

WELCOME ADDRESS

Dr. McElroy
Deputy Director:
NASA-Goddard Space Flight Center

Good morning, ladies and gentlemen. I must say it is a very great pleasure on my part to be able to welcome you to this 12th PTTI conference.

This is the sixth time Goddard has hosted the PTTI and we always welcome the opportunity to do so. It is a personal pleasure because some years ago, about 10 or 15 or so, I was in the organization which housed the hydrogen maser program here at Goddard and I know the spirited discussions which came out of the previous PTTI's and related meetings. Harry Peters and Vic Reinhart and many of the others used to come back from those meetings with many interesting stories. And if this meeting is as spirited as some of those that they told me about, then I am sure it will be a very successful meeting.

I recall the subject of wall effects on hydrogen masers being a popular one for many years. I remember the vigorous arguments that went on as to whether a hydrogen maser would ever be good for anything. But we seem to have passed that stage these days.

There are a number of NASA papers that will be presented over the next three days that will discuss much of what we do here at Goddard in the Precision Frequency and Time fields, but I would like to mention just a couple of those activities and highlight them because we are, indeed, quite proud of them.

Our new hydrogen masers are now becoming available for direct support of the study of crustal movements where accuracies of less than one centimeter per year are required over distances of hundreds to thousands of kilometers. Over the next 4 years we expect to construct three to four of the NASA research or NR masers per year. These added to our existing NASA prototype, or NP masers, will give us about 15 hydrogen masers for support of various NASA programs.

These new NR masers, which have frequency stabilities of a few parts in ten to the fifteenth are under microprocessor control and will be monitored and controlled from Goddard.

The experimental work is continuing in this area with the development of variable volume masers, I am sure a subject which is of great interest to many of you, and a new field operable maser design which should be reproducible at a much lower cost than present designs, and picking up on Dr. McCoubrey's comments, hopefully with a lot higher reliability as well.

Our interferometry work continues with the use of the Mark III wide band, very long baseline interferometry systems. These systems are currently located at Westford, Massachusetts, Greenbank, West Virginia, Owens Valley, California, Fort Davis, Texas, and Onsala, Sweden.

A portable system has already been out to Germany and to England and is now presently at Goldstone, California.

The velocity measurement goals of the crustal dynamics project are accuracies of 4/10 of a centimeter per year for a 5-year measurement span and 7/10 of a centimeter per year for a 3-year measurement span.

To date we have been able to achieve an RMS value of three centimeters between Haystack and Owens Valley, a distance of 4000 kilometers over a 4-year period.

During the 1980's we are going to replace most of our worldwide ground tracking network with two large geostationary communication satellites, the Tracking and Data Relay Satellite System.

The TDRSS, as it is called, will greatly increase spacecraft communications capability, but will also be used to time synchronize the TDRSS ground terminal at White Sands, New Mexico to terminals here at Goddard and, thus, to the U.S. Naval Observatory to within some 100 nanoseconds.

In cooperation with the Naval Research Laboratory we are developing GPS timing receivers that will be used in our laser ranging network for sub-microsecond timing in support of the crustal dynamics project.

All of these activities, I think, show that Goddard is, indeed, very interested in the subject of this conference.

We have some very distinguished guests here today from other PTTI sponsoring agencies. Among them we have Rear Admiral Eustace, who is Vice Commander of the Naval Electronic Systems Command, Captain Vohden, who is the Superintendent of the Naval Observatory, and Captain Henifin, Commanding Officer, Naval Research Laboratory.

I would also like to welcome and acknowledge the attendance of our foreign guests. Many of us in our own travels are hosted and treated extremely well when we visit laboratories around the world and we are certainly delighted to have the opportunity to reciprocate at least in a small fashion.

Of the 44 papers in the program, 10 are from authors from other countries. Certainly your presence at this meeting makes for a much more meaningful discussion and you are indeed welcome.

I thank you all for coming and for the opportunity to greet you this morning and I sincerely hope that you have a very good 3 days.

OPENING COMMENTS

Rear Admiral R. J. Eustace
Vice Commander
Naval Electronic Systems Command

REAR ADMIRAL EUSTACE: Thank you, Dr. McCoubrey. Good Morning ladies and gentlemen. I want to join in welcoming all of you here today and particularly our foreign guests, as was noted.

It is a pleasure to be here as a representative of the Naval Electronic Systems Command because we are one of the cosponsors of this 12th Annual Precise Time and Time Interval Applications and Planning Meeting.

NAVELEX is the Navy's PTTI program manager. As such we are, of course, a vitally interested member of this community. We understand the problems confronting you and by sharing our problems with you we hope to achieve something from our collective efforts.

We at NAVELEX supply the Navy's fleet with electronic communications, navigation, and command and control systems. These systems have very demanding time and time interval requirements. The systems are constantly being modernized and replaced with newer systems which have even more strigent and demanding timing requirements.

It is only through your efforts to develop new, more accurate, reference standards and time dissemination and distribution systems and techniques that we in NAVELEX are able to support the demands of our fleet.

In scanning your agenda I noted that reliability is the subject of the first session. This is putting first things first. We, in the Navy, are concerned with systems that work; we have too many that don't. We need reliable support systems, including PTTI reference standards and distribution systems.

Like you, I will be interested in hearing what Mr. Willoughby and the other speakers have to say concerning the reliability requirements and capabilities.

I also note that Government PTTI planning and industry's response to that planning is high on the agenda. Again, I concur, that is the kind of dialogue which is extremely important if we in the Navy are to fulfill our increasingly demanding mission.

I encourage each of you to take full advantage of the opportunities you will have during the next three days to keep abreast of the rapidly advancing technology.

Before finishing, I would like to make two announcements which I think you will find of interest. First, in response to NAVELEX's recommendation, the Chief of Naval Operations has validated the Navy's requirement to maintain time on the Global Positioning System satellites to within 100 nanoseconds relative to Coordinated Universal Time. That requirement has been forwarded to the GPS Program Office.

Also, just last month, the Chief of Naval Operations approved the continued maintenance of time on the current TRANSIT satellites to 20 microseconds at a one Sigma relative to UTC.

It is our belief that the maintenance of time in these satellites to within these tolerances will provide the Navy, the other services, and the civilian community with an essential, valuable reference source.

I am certain you will find this planning meeting to be mutually profitable and productive. I am equally certain that the NASA people will again prove to be commendable hosts. It has been my pleasure to welcome you and to thank you for participating.

OPENING COMMENTS

Captain Raymond A. Vohden

Superintendent, U. S. Naval Observatory

CAPT VOHDEN: Mr. Chairman, Ladies and Gentlemen: This morning I have the pleasure of speaking for Admiral Williams who, regrettably, had a previous commitment as the guest speaker for the Annual Meeting of the American Institute of Aeronautics and Astronautics. Admiral Williams wears two hats, he is the Director, Naval Oceanography Division (OP-952) and the Oceanographer of the Navy, both in the Office of the Chief of Naval Operations. He is responsible for people and money resources for the Naval Observatory and he is my boss. As OP-952, he has the task of coordinating the entire Navy PTTI effort. In this capacity, he monitors precise time and time interval functions pertaining to Verdin, Communications, Navigation and the Master Clock Upgrade.

We at the Observatory are optimistic about the future of PTTI in the Navy in that Admiral Williams brings to his position a unique expertise and enthusiasm. At 12 years of age, Admiral Williams was already an accomplished navigator. A graduate from the Naval Academy in 1951, he has served as a navigator on a destroyer; he had three tours on ballistic missile submarines, once as the executive officer and twice as commanding officer. More recently, he served in the Office of the Secretary of Defense as Military Assistant to the Deputy Director, Strategic and Space Systems. At the Observatory we are convinced that, under his leadership, PTTI is on the ascendancy.

Although I have learned a great deal about "time" in the last year as the Superintendent of the Naval Observatory, I find that the more I know the more there is to learn.

The requirements for precise time continue to be more demanding, consequently the Naval Observatory continues to look for means to improve time transfers and to make the U. S. Master Clock more precise and more accessible. The upgrading of the Master Clock continues and we hope to guarantee one (1) nanosecond real-time precision. A prototype Global Positioning System (GPS) receiver has been checked out by the Naval Observatory and time transfers of 30 nanoseconds anywhere in the world are now possible. The monitor results are available on the Naval Observatory's digital information service within less than 24 hours. Of almost equal importance is the speed with which the time service information can reach the user. This year we inaugurated a new digital information service with direct access to parts of our data base and with real-time measurement capability.

While preparing my welcoming remarks, I thought it might be useful to review the proceedings from the past 11 meetings. It was interesting to discover that the original purpose of the first conference was not to duplicate the typical engineering meeting where the emphasis is on papers about new work and accomplishments but, rather, its purpose was to be a planning meeting to reveal if we were meeting all of the PTTI requirements and to determine what could be done better. The emphasis was on capabilities and user needs. Questions and discussions were indispensable to the success of those meetings. Therefore, again, I suggest to you the importance of questions and discussions as the best means to assure the optimum amount of communication among all participants. This should also lead to suggestions to PTTI users for new applications, procedures and techniques and will allow the PTTI researchers to assess fruitful directions for future research efforts.

The Naval Observatory, located on Massachusetts Avenue in Northwest Washington, is well worth a visit for those of you who may not have been there already. Besides being a place of considerable scientific interest, it is a rather pleasant place to visit. In its present location, the Observatory dates back to 1893. It was originally known as the Depot for Charts and Instruments and was founded on December 6, 1830. And for this reason, we will have the opportunity to celebrate our 150th Anniversary on December 6 of this year. A tour of the Naval Observatory is scheduled for the evening of December 2. I'm sure you will find the tour a very interesting and worthwhile experience.

You appear to have a very impressive program outlined for the next two days. I'm sure you are going to have a very productive meeting. Thank you.

OPENING COMMENTS

Captain E. E. Henifin
Commanding Officer
Naval Research Laboratory

CAPTAIN HENIFIN: Good Morning ladies and gentlemen. It is a distinct pleasure for me, on behalf of the Naval Research Laboratory, to make some brief comments at the 12th Annual Precise Time and Time Interval Applications and Planning meeting.

First a sincere thank you to Tom Young and NASA Goddard for providing the fine facilities of the Goddard Space Flight Center for the meeting. Many of you may have been expecting the meeting to be at NRL this year and I apologize if you are disappointed. However, a spurious pulse in the alternating GSFC/NRL hosting circuit has caused a phase shift.

Secondly, I would like to extend to Captain Vohden, Dr. Westerhout, and to all of the employees, past and present of the Naval Observatory, a heartly happy 150th birthday and may the present lead to a bright, prosperous and timely future.

Thirdly, I would like to offer a welcome to the office of the CNO and to the National Bureau of Standards, the sixth and seventh sponsors of this meeting joing with USNO, NASA/GSFC, NAVELEX, DCA and NRL in insuring PTTI continuance.

Back in April 1969 when USNO alone sponsored the first PTTI, it's purpose was to provide a forum for discussion and coordination among Government planners. It was soon expanded to take advantage of valuable inputs from industry and foreign participants.

That original purpose remains today and it may not be the formal sessions that are of underlying importance rather it may be the informal face to face, eyeball to eyeball discussions between sessions, at coffee breaks, and at the social functions that pay the real dividends. And when the meeting is over no one will really know the value of this meeting. But exchange of ideas between planners, users, and doers is priceless. We at NRL are firm believers that meetings, small or large, are a necessity for the exchange of IDEAS.

The formal sessions and papers are the means to facilitate thinking, to generate questions, to formulate new ideas. Hence the attendees, you in the audience, need to be listners, good listeners so that each of you can put the speakers on the spot with the hard and difficult questions that may develop new ideas. I charge you not to be passive attendees but to be active participants.

I believe the Program Commitee has put together an excellent series of sessions, each with a superb group of papers and you should be on with the program.

Thank you for coming and I hope you have a rewarding three days here at Goddard.