

PROCEEDINGS
OF THE
FIFTH PRECISE TIME AND TIME INTERVAL PLANNING MEETING

Held at Goddard Space Flight Center
December 4-6, 1973

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CALL TO SESSION

Dr. William J. Klepczynski, NAVOBSY

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Dr. John F. Clark, Director, GSFC

OPENING COMMENTS

Dr. K. Aa. Strand, Scientific Director, NAVOBSY

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PROCEEDINGS OF THE FIFTH PRECISE TIME AND TIME INTERVAL PLANNING MEETING

FOREWORD

This volume contains the papers presented at the Fifth Annual Precise Time and Time Interval (PTTI) Planning Meeting. The meeting was sponsored jointly by NASA/Goddard Space Flight Center, the U. S. Naval Observatory, and the U. S. Naval Electronic Systems Command. The meeting was held December 4-6, 1973 at Goddard Space Flight Center.

The purposes of this meeting were to:

- a. Disseminate, coordinate, and exchange practical information associated with precise time and frequency;
- b. Review present and future requirements for PTTI; and
- c. Acquaint systems engineers, technicians, and managers with precise time and frequency technology and its problems.

More than 300 people participated in the conference. Attendees came from various U. S. Government agencies, from private industry, and from several foreign countries and international laboratories. Twenty-eight papers were presented at the meeting, covering areas of navigation, communications, applications of interferometry, frequency and time standards and synchronization, and radio wave propagation.

Abstracts are presented for three papers given at the meeting for which no written paper was received. One paper, which was not presented at the meeting because the author was unable to attend, is contained herein.

It was readily apparent that the close communication and cooperation that was established between various Government agencies, private industry, and international laboratories at previous meetings has been maintained.

Many contributed to the success of the Meeting. On behalf of the Executive Committee of the Fifth PTTI Planning Meeting, I wish to acknowledge the Session Chairmen, speakers and authors, the members of the Technical Program Committee and Editorial Committee and the many others who gave freely of their time.

Copies of the Proceedings may be obtained by sending a request to:

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Dr. William J. Klepczynski
General Chairman

INTRODUCTION

MR. WARDRIP: I am Clark Wardrip, from Goddard. I welcome you here this morning. I see many of you that were here last year, and I welcome you again.

In view of the fuel shortage and the cutback on air transportation, and the general restriction on government travel, I am gratified to see so many of you here this morning.

I think the attendance speaks well of the PTTI Planning meetings, and the importance that upper management places on these meetings.

As last year's chairman, it is my privilege and also a personal pleasure for me to introduce this year's chairman, Dr. William Klepczynski, of the U. S. Naval Observatory.

Bill has double-duty this morning. He is also chairman of Session I.

So, Bill, I would like to pass control of the meeting to you.

DR. KLEPCZYNSKI: Thank you, Clark.

CALL TO SESSION

William J. Klepczynski
U.S. Naval Observatory

DR. KLEPCZYNSKI: It is my great pleasure to call to session this Fifth Annual PTTI Planning Meeting. There are a few brief introductory remarks concerning this meeting which I would like to make.

The first concerns the organization of the papers on the program. For each of the three days of the meeting, the papers are grouped together according to the following general categories:

The first day of the meeting is devoted to PTTI requirements, applications, and systems.

The second day is concerned with time dissemination, clock calibration, and precision frequency sources.

The third day is devoted to VLF transmissions for time synchronization, and PTTI requirements for communications.

I believe the technical program committee did an excellent job in selecting the papers on the program. However, if anyone feels that certain topics are not adequately covered, please contact any member of the executive committee during the course of the meeting, and make your preferences known. They will be taken into consideration for the next PTTI Planning Meeting.

One of the most important benefits of a meeting of this type is the gathering together of many knowledgeable and interested parties. Because of this, I urge all attendees to partake in the discussion periods, or engage in private discussions. If this is not done, then I am afraid that one of the benefits of such a gathering of expertise will be lost.

It is important to take note of the increased participation of representatives of foreign laboratories in this meeting. PTTI is one of those unique fields which not only brings together scientists and engineers of different fields of specialization, but also scientists and engineers of different countries.

Today, we have in our audience representatives of Australia, Canada, Germany, Italy, Taiwan, and the United Kingdom.

On the program tomorrow, we will have three internationally known scientists discussing the work done at their laboratories, Mr. Humphrey M. Smith of the Time Department of Royal Greenwich Observatory, Professor S. Leschiutta, Istituto Elettrotecnico Nazionale, the IEN, Torino, Italy, and Dr. E. Proverbio of the International Astronomical Latitude Station at Cagliari, Italy.

I am sure that we will all benefit from hearing first-hand the work being carried on at these facilities.

It is now with great pleasure that I now call upon Dr. John F. Clark, the Director of Goddard Space Flight Center, for our welcoming address.

WELCOME ADDRESS

John F. Clark, Director
Goddard Space Flight Center

DR. CLARK: Good morning, ladies and gentlemen. It is a real pleasure on behalf of the center to welcome you here.

I must confess, I haven't quite gotten over our date with the large planet last night. Many of us were out here until close to midnight. I think it was a disappointment only to those people who had hoped to be able to see enough real time rectified photography to be able to get out and just about crawl down into that Red Spot. Everything else about it was spectacular, as befits that giant lady.

Incidentally, I heard a new word this morning on the Today Show. John Wolfe, the project scientist at Ames was talking about what had been learned overnight, and he used the word "geochauvinism" to talk about the view that those of us who grew up about Earth have about another planet and what we should see as we come close to it.

It requires a lot of patience to get some of the rectified pictures. We saw the first one of those last night, taken about a week ago, and this morning they had another one which, unrectified, looked to the unaided eye as a somewhat distorted home black and white television picture. This rectified picture had about twice as good a resolution as the best of the previous ground base photography.

So, I for one am looking forward to this with some excitement.

Many of you may know that Goddard is one of NASA's eight major field centers. NASA Headquarters is in Washington, D. C. Goddard has prime responsibilities in the areas of space science and applications, and in network mission and data operations.

It is particularly in these latter areas that we find our principal affinity with precise time and time interval measurements.

From early days, starting in 1958 when NASA was formed and this center came into being officially, Goddard people have been very active members of this time and frequency community, and I think our contribution to this field, as you will hear in some of the papers today, has been significant.

From Project Vanguard to the present, we have had close cooperation with DOD in many fields, particularly in the time and frequency area.

You folks have established a communication and mutual data exchange that has been beneficial to the entire scientific community, as is evidenced by this conference today.

In particular, Goddard has maintained very close cooperation with the Naval Research Laboratory, from whence many of our people migrated, and I must say in looking over the program I notice that your chairman of Session VI was a roommate of mine too many years ago when we both worked at NRL.

The assistance of the United States Naval Observatory in transporting time to some of our tracking stations in support of Apollo is very much worthy of mention, as is the use by NASA of the time broadcast and VLF transmissions from the stations of the National Bureau of Standards, and the Loran-C stations of the Coast Guard.

You may recall that up until a few years ago, radio station WWV was next door to Goddard. We certainly had no problem receiving time then. All we really had to do was hold up a finger.

We have all seen over the last decade accuracy requirements for time tightening: seconds, to milliseconds, to microseconds.

In the near future—almost the present—it looks even tighter, requiring fractional nanoseconds, both in laser geodesy and very long baseline interferometry.

Frequency stability requirements have advanced from a few parts in 10^9 to the 9th to parts in 10^{10} to the 13th or better. I suspect only you can imagine what the more distant future requirements are going to look like.

We at Goddard look forward to continuing cooperation in this very interesting field, and therefore it is with pleasure, as your host, that I welcome you to this conference, and I look forward to participating as I am able.

Thanks very much.

DR. KLEPCZYNSKI: Now, for some opening comments from Dr. K. Aa. Strand, who is the Scientific Director of the Naval Observatory.

OPENING COMMENTS

K. Aa. Strand, Scientific Director
U. S. Naval Observatory

DR. STRAND: Good morning, ladies and gentlemen.

On behalf of the U. S. Naval Observatory it is my pleasure to extend a hearty welcome to the participants of the Fifth Annual PTTI Planning Meeting.

Since the Observatory's humble start as the Depot of Charts and Instruments in 1830 it has been continuously involved in the determination of time. Over the many intervening years the Observatory has achieved many firsts, both in astronomy as well as in time and time interval as such.

The Observatory has in this manner served not only the Navy, but also the Nation, for nearly 150 years, while at the same time contributing to many international undertakings in science.

Let me briefly mention a few contributions the Observatory had made in the field of time and frequency.

In 1845 the Observatory began its first time signals by dropping daily at noon a time-ball from its roof.

In 1865 the Observatory commenced sending time signals to fire and police stations in Washington, and since 1877 to Western Union for nation-wide distribution. In 1904 the first operational radio time signals were transmitted by a Navy Radio Station with the time signals controlled by the Observatory.

In 1958 the Observatory established the duration of the atomic second in an experiment conducted jointly with the National Physical Laboratory, Teddington, England.

In 1962 the first high precision time transfer was accomplished between the Naval Observatory and the Royal Greenwich Observatory using the Telstar Satellite, a technique which has now become an essential link in the overall timing system. Finally, since 1960, the Observatory has used ensembles of clocks as the basis for an extremely precise and reliable atomic time scale. This atomic time and the principles of its operation have now become an important contributor to the international atomic time kept by the BIH.

When the Observatory began its time determinations, it was able to do so with an accuracy of 0.1 second, which corresponds to a frequency precision of one part in a million per day. Now our scale is stable to four parts in 10^{14} per day, an improvement of 25 million times.

It is now my pleasure to introduce to you Captain Earl B. Fowler, Deputy Commander, Material Acquisition Directorate, of the Naval Electronic Systems Command.

Captain Fowler is a graduate in mechanical engineering from Georgia Tech, and holds an electrical engineering degree from MIT. Since time does not permit me to describe his distinguished career in the Navy, I shall simply turn the rostrum over to Captain Fowler, who will speak on the Naval Electronic Systems Command's responsibility for PTTI within the Navy Department.

OPENING ADDRESS

Earl B. Fowler, Jr.
Naval Electronic Systems Command

CAPT. FOWLER: Thank you Dr. Strand.

It is my pleasure to be here this morning at Goddard after some years. A few years ago I was the project manager for the construction of the five ships for the support of the Apollo Program. I enjoyed that association with this organization.

It is my great pleasure to be here this morning representing Rear Admiral Raymond J. Snyder, United States Navy, Commander of the Naval Electronic Systems Command, one of the co-sponsors of this meeting.

I want to welcome each of you, especially our distinguished guests from Europe and the Orient.

Again this year, the Naval Observatory, the Naval Electronics Systems Command, and NASA Goddard Space Flight Center are co-sponsoring this event, which brings together many of the national and international agencies with responsibilities and interest in PTTI.

The Naval Electronic Systems Command is a worldwide organization, with headquarters here in Washington. It is a fast growing, dynamic command, supplying many of the electronics needs of the operating forces.

We were founded in 1966, and we are still a youthful organization. We do not enjoy the tradition and longevity of the 150 years that the Naval Observatory does, nor the contemporary exploration of unknown planets as our friends here at Goddard.

Originally, our responsibility was limited to shore electronics, remote sensors, special communications for submarines, navigation aids, and ocean surveillance.

But during our seven year history, we have expanded to include command controlled communications, reconnaissance, electronic warfare, special operations intelligence, and tactical electro-magnetic warfare, and we are still growing. We have about a billion dollar budget now.

The Naval Electronic Systems Command has been designated the Navy manager for PTTI, including planning, programming and budgeting for research development, procurement, and life cycle support.

In addition, the Naval Electronic Systems Command assists the Naval Observatory in its job of PTTI manager for the Department of Defense.

We are responsible for updating PTTI systems.

The presently accepted method for synchronizing clocks is through our portable clock service, which consists of teams carrying clocks to sites for calibration as required.

The cost in dollars and people necessary to provide this synchronization service is a problem.

To provide better precision at a lower cost, we, in cooperation with the U. S. Naval Observatory, and the Naval Research Laboratory, have developed a concept of time distribution utilizing long range transfer of PTTI via existing satellite systems, short range transfer via microwave lengths, and local transfer via hardware or optical systems.

The PTTI program has been progressing under this concept of operations, proving the feasibility of utilizing various methods of time transfer, so that ultimately a network of redundant paths will be available to users who can synchronize their clocks to a common source, normally the U. S. Naval Observatory Master Clock.

Navy application of precise time and time interval technology includes navigation and ship positioning, increasing the efficiency of point to point digital communications, and assuring that the crystal oscillators and synthesizers are precise.

The digital data rates of a given communications system under precise control can perhaps go up from 2,400 Baud to as high as 9,600 Baud, or better. However, the confidence of these rates directly depends on absolute accurate knowledge of the Baud-to-Baud time record.

International color television transmission can also profit from this knowledge. For example, in order to bring in real time color television at both ends, the oscillators and color separators must all be accurately synchronized.

Other potential uses of PTTI include effective collision avoidance systems for aircraft, more efficient use of radio frequency spectrum, further long line communications efficiency, and time correlation of distant geodetic and geologic astronomic events.

The overriding objective of the Naval Electronic Systems Command PTTI program is to disseminate PTTI utilizing wherever possible existing electromagnetic systems and to provide a common reference to most Department

of Defense users, and above all, to effect standardization of time and frequency to the best of our ability.

The exchange of ideas and the dissemination of information at these PTTI meetings, which advance this objective, will certainly have some influence on decreasing proliferation of equipment and upcoming systems.

This way, we will encourage maximum use of existing capabilities, and this means cooperation with others.

I think I can underscore that last one, as I look to the future budgets, and what we are going to be able to do, and say that cooperation and maximum use of what we have is going to be the keynote.

I am sure that our NASA hosts are going to provide us with a very enjoyable and informative session, and I thank you very much and wish you the very best in your meetings to come.

DR. KLEPCZYNSKI: I thank our opening address speakers for the very informative insight into what goes on at the various installations.

At this time, we will start with Session I.

The first paper is entitled "Defense Mapping Agency Precise Time and Time Interval Requirements." The speaker was scheduled to be Rear Admiral Carnahan. However, he is recuperating from an operation and was not able to make it, but the Assistant Director for Plans and Requirements, Mr. O. W. Williams, will give his paper for him. You will also hear from him later on today.