X-814-73-72

PROCEEDINGS

OF THE

FOURTH PRECISE TIME AND TIME INTERVAL PLANNING MEETING

Held at Goddard Space Flight Center
November 14-16, 1972

Compiled by
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Second Printing

Sponsored by
NASA Goddard Space Flight Center (GSFC)
U. S. Naval Observatory (USNO)
U. S. Naval Electronic Systems Command (USNESC)

Prepared by
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Greenbelt, Maryland 20771

FOREWORD

This volume contains the papers and panel discussions presented at the fourth 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 at Goddard Space Flight Center on November 14-16, 1972.

The objectives of the PTTI Planning Meetings are to:

- Disseminate and coordinate information at the user level associated with PTTI
- Review present and future PTTI requirements
- Inform Government engineers, technicians, and managers of precise time and frequency technology and its problems
- Provide an opportunity for an active exchange of new technology associated with PTTI

The proceedings are arranged into three sessions, namely:

I. Satellite Timing Techniques, Precision Frequency Sources, and VLBI applications.

II. Frequency Stabilities and Communications

III. VLF -UHF, Propagation and Use

A panel discussion on the papers and related subject matter was conducted by the session chairman after each session. The panels were composed of experts in the field covered by the particular session.

More than 300 people participated in the conference, either as attendees or registrants. Attendees came from the U. S. Government, from private industry, and from several foreign embassies. Twenty-eight papers were invited for presentation, covering areas of navigation, communications, satellite tracking, interferometry techniques, radio wave propagation, and frequency and time generation and synchronization.*

It is the hope of this year's PTTI officers that the close communication and cooperation that has been established between the various Government agencies will be maintained, perpetuated, and expanded to cover other PTTI-related fields in future meetings.

*"Use of Precise Time and Frequency Standards in the Very Long Baseline Interferometer Investigation of Celestial Radio Sources," by K. H. Johnston and S. H. Knowles of the Naval Research Laboratory, was presented but is omitted from these Proceedings.

It is with great pleasure that we acknowledge the support and contribution of the officers, session chairmen, panelists, speakers, and authors, and the many others who contributed to the success of this year's PTTI meeting.

Copies of the proceedings may be obtained from either the Goddard Space Flight Center or the U. S. Naval Observatory by sending a request to either:

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Capt. John C. Bajus, NAVELECSYSCOM

Session I Chairman
Andrew R. Chi, GSFC

Session II Chairman
Dr. William Klepczynski, USNO

Session III Chairman
Dr. Gernot M. R. Winkler, USNO

Panel Discussions

Session I

Discussion Coordinator: *Andrew R. Chi,* GSFC

Panel Members:

Dr. Carroll O. Alley, Maryland University
Dr. William J. Hurd, JPL
Dr. Stephen E. Knowles, Maryland University
Dr. Arthur A. McCubbrey, Frequency and Time Systems, Inc.
Peter F. MacDoran, JPL
Dr. Jayaram Ramasastry, GSFC

Session II

Discussion Coordinator: *Dr. William J. Klepczynski,* USNO

Panel Members:

Lauren J. Rueger, APL
Dr. Gernot M. R. Winkler, USNO
Dr. John E. Lavery, GSFC
James A. Murray, Jr., NRL
Harold C. Polts, NCS
Jay R. Curtright, JPL
Robert R. Stone, Jr., NRL
Cdr. William E. Harrell, NESC
Eric R. Swanson, NELC
Dr. James C. Morakis, GSFC
John T. Stanley, NBS

Session III

Discussion Coordinator: *Dr. Gernot M. R. Winkler,* USNO

Panel Members:

Dr. Frederick W. Rohde, USATOPOCOM
Eric Swanson, NELC
Dr. Friedrich H. Ender, USATOPOC

Panel Members Continued:

Dr. James Crouchley, Queensland University, Australia
James Britt, NELC
Andrew R. Chi, GSFC

OPENING ADDRESS

Laverne R. Stelter
Goddard Space Flight Center

On behalf of Dr. John Clark, the Director of Goddard Space Flight Center, I would like to welcome you here this morning. To those of you that have come in from out of town, I'm sorry about the wet weather. While driving into work this morning, I heard the weatherman report that the rain should stop by noon. Now, if the weatherman dealt with such precise subjects as time, he would be more accurate. We do hope the weather improves and that your stay here is a good one.

I would like to tell you briefly about what we do here at Goddard, especially for the benefit of those of you who have not been here before. And I would also like to tell you why we consider time and timing a very important subject.

There are about 4200 people here at Goddard, and about two-thirds of them are involved in managing, preparing, and launching earth-orbiting satellites. These satellites fall into two basic categories: the scientific type, for astronomy, earth physics, and so on – satellites like the Orbiting Solar Observatory (OSO) series; and the application satellites, such as the Advanced Technology Satellite (ATS) series, weather satellites like Nimbus, and more recently, the Earth Resources Technology Satellite (ERTS-1).

I might add that in many cases the satellite experiment instruments are built in-house here at Goddard, and in some cases the smaller satellites are actually constructed here. And most are also tested here. Those of you who take the tour Thursday will see the environmental test facilities – the classic "shake and bake" facilities.

The other one-third of the people here are involved with the ground-operations end of the business. This breaks down into two major categories – the tracking and data-acquisition function, and the data-processing function. Those of us in networks are involved in the engineering and operation of tracking stations around the world, with the global communications net that ties these stations together, and with the project control centers that take care of the health and maintenance of the spacecraft themselves.

Again, those of you who go on the tour will also see the heart of our communications net. You will also see a number of project control centers. From some of these centers, the earth-orbiting satellites are physically controlled.

The subject of timing is a very important ingredient in everything we do here. Speaking from personal experience, I first got involved with timing – and this may sound like some time ago, considering the young faces in the audience – back in the early 1950s. I was a red-hot engineer, just out of college, and one of my very first jobs in the U.S. Army Signal

Corps was to put out into the field a better way to measure frequency at our point-to-point transmitter and receiver station.

So I did a two-month survey of what was available in the state-of-the-art and ended up with General Radio frequency-measuring equipment. It was actually two racks of equipment, including a longitudinal-oscillating 100-Kc crystal, heterodyne oscillators, and so forth. The crystal was good to about one part in 10^6. This equipment was sent to the field and I remember thinking at the time that it was quite an achievement to consistently measure the output frequency of a transmitter operating in the HF band with an accuracy of better than 100 hertz.

Well, that was just about 20 years ago, and many advances have been made since that time. During Apollo-17 for instance, we measured the position of the lunar rover with respect to the lunar module to a positional accuracy of about one meter on the lunar surface. To do that, the frequency standards in use today in the tracking stations must have a short-term stability on the order of about one part in 10^{12}. We used the very long baseline interferometer (VLBI) technique and measured the relative arrival time of the wavefronts of the signals from the lunar module and from the lunar rover. Therefore, in 20 years, we've come a long, long way.

We see no end to the demand for very precise measurement of time, which is also obviously related to very good frequency stabilities. As we move into the area of very high precision orbit determination, techniques involving the measurement of lunar libration, and so forth, we are going to require better and better precision in everything we do.

It is conferences such as this that we feel are extremely beneficial in allowing interchange and exchange of information. We look forward to a continuing cooperation with all of you in attempting to further PTTI capabilities. We feel that a forum such as this goes a very long way in promoting advances in the state-of-the-art.

Once again, welcome to Goddard. We hope your stay here is a pleasant one. If there is anything we can do to help you out, let us know. We will do our best to accomodate you.

Thank you very much.

INTRODUCTION

John C. Bajus
U. S. Naval Electronics System Command

As a professional Naval officer and operating engineer, I want to welcome you on behalf of the U.S. Navy to this fourth Precise Time and Time Interval (PTTI) Planning Conference.

The two sponsoring agencies of the U. S. Navy, the U.S. Naval Observatory and the Naval Electronics Systems Command, are very fortunate this year to enjoy the co-sponsorship of the NASA/Goddard Space Flight Center. In particular, I want to express my appreciation to Dr. Clark and the people at Goddard for allowing us to utilize this beautiful facility. Thank you for your generous contribution to this conference.

One of the main reasons for this PTTI Planning Conference is the exchange of practical information. Therefore, I would like to discuss the recent changes within the Navy relative to management of this important aspect of our daily lives.

The Naval Observatory, like other government organizations, is resource limited, and even more so in these days. Its responsibility as the PTTI manager for the Department of Defense is in itself a full-time-job. In the past, this dual role of Naval Observatory and Department of Defense manager has caused some problems, especially at tri-Service meetings. Therefore, in order to improve the situation, the Chief of Naval Material, Admiral Kidd, has been charged with the Navy management responsibility, and he is in the process of redelegating these responsibilities to us in the Naval Electronics Systems Command. This, we hope, will strengthen the Naval Observatory's capabilities for the execution of their proper mission. Which means, in the PTTI area, essentially the following:

- Provision of the time standard
- Management and consultation regarding the overall Department of Defense precise time and time interval effort
- The distribution of precise time and time interval down to the next level in the PTTI hierarchy, that is, to the precise time-reference stations

The Naval Electronics Systems Command will assume these additional management responsibilities for the Navy, including planning, programming, and budgeting for the complete research development and on into total life-cycle support. In addition, the Naval Electronics Systems Command will assist the Naval Observatory in the execution of its responsibilities as the manager for the Department of Defense.

As examples, we can mention the current effort to upgrade the time distribution over LORAN-C and the proposed establishment of precise time-reference stations at certain satellite communications ground terminals.

The choice of our command, NAVELECS, for this role is proper because of our expanding responsibilities in the Naval Material Command for command and control communications underseas and for space surveillance, navigation, and recently, electronics warfare. Each of these system areas will require PTTI as an indispensible element. Furthermore, it is the only common base for achieving integrated communications navigation and identification systems, and other such system concepts that cut across many electronics systems.

While NAVELECS has been charged with these additional responsibilities without a concomitant increase of resources, we welcome this challenge to do a good job and we will try our best to do so, for the Navy's operational requirements demand it.

In many tactical situations we find it is mandatory that several Department of Defense components be synchronized to a high order to complete a mission. We have to be on time. And I trust as we continue our deliberations these few days that we will maintain our time schedule. I sincerely hope that this conference will help us all in this endeavor.