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PROCEEDINGS
OF THE TENTH ANNUAL
PRECISE TIME AND TIME INTERVAL
(PTTI)
APPLICATIONS AND PLANNING MEETING

Held at the Naval Research Laboratory

November 28–30, 1978

Sponsored by

Naval Electronic Systems Command
NASA Goddard Space Flight Center
Naval Research Laboratory
Naval Observatory
Defense Communications Agency

Prepared by
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BANQUET SPEAKER

Dr. R. Grant Athay
High Altitude Observatory, Boulder, Colorado
Subject: Mysteries of the Sun

CALL TO SESSION

Dr. Gart Westerhout
Scientific Director, Naval Observatory

WELCOME ADDRESS

Capt. Edward E. Henifin
Commanding Officer, Naval Research Laboratory

OPENING COMMENTS

Tecwyn Roberts
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FOREWORD

These proceedings contain the papers presented at the Tenth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, including questions and answers following the presentations.

As stated in the Program Introduction, the purpose of the PTTI Applications and Planning Meeting is:

To give PTTI Managers, Systems Engineers, and Program Planners:

- A transparent view of the state-of-the-art
- An opportunity to express needs (current or future)
- A view of important future trends
- A review of relevant past accomplishments.

To provide PTTI users with new and useful applications, procedures, and techniques.

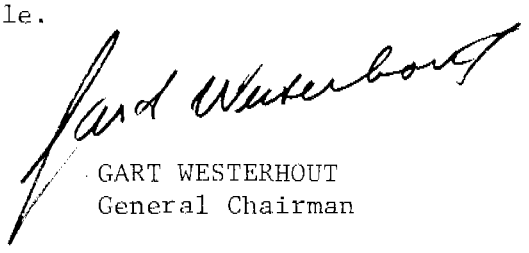
To allow the PTTI researcher to better assess fruitful directions for research efforts.

The 195 registered attendees came from Government, private industry, Universities, and foreign countries.

This year, most sessions were started with invited tutorial papers followed by contributed papers. This format proved very successful; The tutorials set the tone for the following discussions. A successful Discussion Forum on Atomic Frequency Standards was a fitting end to the first day. The tutorials covered the following subjects:

- Composite Oscillator Systems for Meeting User Needs for Time and Frequency
- Quartz Crystal and Super Conductive Resonators and Oscillators
- Time Domain Measurement Systems
- Frequency Domain Measurement Systems
- Clock Performance as a critical Parameter in Navigational Satellite Systems
- Down to Earth Relativity
- Modern Technology for the Determination of UT1 and Polar Motion.

On behalf of the Executive Committee, I want to thank all those who contributed to the success of this year's meeting. Special thanks go to the Chairmen of the Technical Program Committee who carried the major responsibility for this excellent program and to the Session Chairman. Without S. Clark Wardrip, who was on top of absolutely everything, this meeting would have been impossible.



GART WESTERHOUT
General Chairman

CALL TO SESSION

Dr. Gart Westerhout
U. S. Naval Observatory

DR. WESTERHOUT: Good Morning. I am Gart Westerhout, Scientific Director of the U. S. Naval Observatory. As general chairman for this Tenth Annual Precise Time and Time Interval Applications and Planning Meeting, I call the meeting to session.

This year's meeting features 7 tutorial papers, 20 contributed papers and a discussion forum. The executive committee asked the program committee to draw up a program which emphasized the purpose of the meeting: To provide PTTI managers, engineers, planners, users, and researchers with a review of the state of the art and a discussion of needs and future trends. I recommend that you all read page VI in the program booklet again, so that we remember the reasons for this meeting, which is properly called an Applicatons and Planning Meeting. The executive committee does not want this annual affair to become the equivalent of an IEEE type meeting.

Having said all this, I need to thank our technical program committee and especially its able chairman, David W. Allan, for a job well done. Subjects for the tutorials seem very appropriate and will hopefully contribute to the overall discussion as well as to the purpose of the meeting: to assist PTTI Managers, Systems Engineers and Program Planners in their tasks.

I also wish to thank the members of the executive committee for the smooth manner in which this tenth meeting has come into being. I have spent 9 months trying to find out what I was supposed to do as general chairman, and I'm still looking. Everything happened automatically. That's why I feel it incumbent on me to speak to you for half an hour today; at least that gives me something to do.

Thanks are due especially to S. Clark Wardrip of NASA who handled all the details of putting the meeting together, and to James A. Murray and Charles Bartholomew of NRL who handled the local arrangements.

Before I yield the microphone, two comments: Please use the microphone when you are making comments, and state your name and affiliation. Discussion after each paper is very strongly encouraged and the recording of the discussion is considered to make the proceedings extremely valuable.

And the second comment: Wednesday's banquet speaker, Dr. R.Grant Athay, is a world-renowned solar physicist. I warmly recommend attendance at the banquet for both its tangible and intangible benefits.

I would now like to call on the representatives of some of the agencies who sponsor the PTTI meetings to say a few words of welcome.

WELCOME ADDRESS

Capt. Edward E. Henifin
Commanding Officer
Naval Research Laboratory

On behalf of the Naval Research Laboratory, I would like to welcome you to the Tenth Annual Precise Time and Time Interval Applications and Planning Meeting. It is a pleasure for NRL to act as one of the co-hosts and sponsors of this meeting.

You are about to embark on a series of technical sessions for the next three days to accomplish the goals of the meeting. These sessions are going to be extremely interesting and thought-provoking and, since you all are involved in precise time, I'm sure the sessions will all go according to the planned schedule.

Most individuals are clock-watchers of sorts and from our earliest memories time has played an important role in our lives. From my own experiences, my earliest recollection of time and time measurement goes back to the early school years watching the hands of an old Seth Thomas move ever so slowly toward the three-thirty mark when school would be out. Measurement was the number of days until the next weekend or the next vacation - it was not a precise thing - just a block of days divided into various intervals.

Later on, as I became more aware of the importance of time, I realized that my grandfather and father, both railroad engineers, were extremely interested in exact time, especially that which had to do with trains. On a periodic schedule both had to have their big pocket watches checked by a particular jeweler. The watches had to be precise - that is, would not lose or gain more than a few seconds in a month - I can't remember the number now, but that's probably not important.

Then, there was my first watch - used to check it with the radio daily to make sure it wasn't slow or fast. A minute or two a week made me feel pretty good - I had an accurate watch.

Then, I was exposed to navigation. Time and accuracy took on a new dimension. The daily time ticks with WWV and the chronometer log sun lines; apparent noon; star fixes; etc. required accurate time for accurate position reports. In 1968/69 I encouraged my navigator to write a paper up the chain of command proposing that we replace the chronometers on board ship with the then new Bulova Accutrons - they were advertized as being more accurate/precise than the chronometers we had on board - accurate to tenths of seconds in a 30-day period. As you may know, chronometers had to be overhauled every operating

cycle at costs of about three to four times that of an Accutron. Tenths of seconds or even hundredths of seconds are comprehensible to me but comprehending nano and pico seconds is like trying to visualize a billion dollars all in one-dollar bills - mind boggling.

That's a brief of my experience with time, with the exception of this past year when I met the keeper of the time, Dr. Gernot Winkler, at the Naval Observatory and additionally had the good fortune of being briefed on the PTTI program. I won't say that I understand PTTI, but I do have an appreciation for what it is and what your goals, when achieved, will mean.

NRL is proud of the part it has played in the time and frequency field over the years and is looking forward to a continuing contribution in the future.

It is therefore with great pleasure that on behalf of NRL I again welcome you to this conference.

OPENING COMMENTS

Tecwyn Roberts
Director, Networks Directorate, NASA/Goddard Space Flight Center

As some of you may know, 1978 marks the 20th Anniversary of NASA, and I think it appropriate to reflect a few moments about some of what has been accomplished in those twenty years and where we are going, not only in the precision frequency and time area but also in other areas.

From NASA's inception, the Agency has successfully worked both to advance man's knowledge of the universe, and to use that knowledge to better life on Earth. We are proud of Goddard's role in this effort.

Goddard's early work with communication satellites such as Relay, Syncom and the Applications Technology Satellites (ATS) laid the ground work for low cost transatlantic telephone calls and radio and television broadcast.

The key to future growth in satellite communications is the broadcast satellite which beams signals directly to rooftop size terminals. ATS-6 experiments demonstrated that one satellite in a stationary orbit can serve thousands of users.

Goddard's research with metrology satellites has and is revolutionizing the study and forecasting of global weather conditions. Projects managed by Goddard such as the TIROS series of satellites laid the groundwork for the use of satellites for predicting the weather. TIROS-N, which was launched Oct. 13th, has been active mapping the weather and tracking hurricanes; the first of which was Kendra.

In the early 1960's NASA initiated the Nimbus satellite program which was designed to meet the research needs of atmospheric and earth scientists. The final satellite in this series, Nimbus 7, was launched Oct. 24th in a near polar orbit so as to monitor man made and natural pollutants in the atmosphere which concerns us all.

Goddard is also very much a part of the Global Atmospheric Research Program (GARP) which was established in 1967 under the auspices of the United Nations. The first Global Weather Experiment is scheduled to start in December or January. Data will be collected for one year from over 10,000 sources; platforms on the ground, ships at sea, aircraft and weather satellites operated by the United States, Japan, the European Space Agency (ESA), and the USSR.

NASA's Earth Resources Satellites are providing the means for nations to take constant inventory of the Earth's dwindling supply of natural resources. Goddard's role in this program includes the management of the Landsat satellites. These satellites with special sensors are able to distinguish different crops, measure ground temperature, and determine flood patterns, erosion, and drought areas. Last May NASA launched a satellite to map the day/night temperature differences of the earth's surface. The satellite called the Heat Capacity Mapping Mission (HCMM) will be used with temperature information from Landsat 3 to classify rock formations, monitor soil moisture changes and agriculture stress, and study the effects of urban heat islands on local weather.

Next year NASA will launch its first geological applications satellite termed Magsat. The data Magsat sends back will aid in mineral and oil exploration and in updating world and regional magnetic charts used for navigation and surveying.

Other Goddard projects look beyond the Earth to study the influence of the sun on the Earth and observe the stars and planets to learn more about cosmic processes. In 1979, at the height of the next eleven year cycle of maximum solar activity, NASA will launch Goddard's Solar Maximum Mission (SMM) to study the entire electromagnetic spectrum of solar flares to try and determine their physical origin.

It may interest you to know that it was Goddard's Copernicus satellite that this past June located a second invisible black hole in our galaxy orbiting a giant super star. The black hole is gradually siphoning away the larger star's atmosphere. A gamma-ray observatory scheduled for the mid 1980's will look again at black holes as it maps gamma-ray sources throughout the universe. Studying black holes will extend man's knowledge of physics into aspects of relatively not observable here on Earth.

Through the International Ultraviolet Explorer (IUE) experiment astronomers from NASA, the United Kingdom, and the European Space Agency are continually looking at objects ranging from planets in our solar system to the most distant objects in the universe. Another experiment planned for 1983, the Cosmic Background Explorer Satellite, will use infrared waves to address the question of the very origin of the universe.

Coming to more earthly aspects, in the early 1980's the Space Shuttle will begin making round-trips into space. Eventually, there is expected to be as many as forty missions per year. For Shuttle, Goddard is developing a standardized satellite container called a Multimission Module Spacecraft that can house a diversity of experiments and instruments.

Goddard also has the responsibility for administering the Shuttle Getaway Special Program. Through this program, individuals, industries, research groups, and other nations can place small experiments aboard Shuttle for as little as $3000. In fact, Goddard's Explorer Scout Post is planning a project on Shuttle via this program.

In the early 1980's Goddard will replace most of its present worldwide ground tracking network with two large synchronous communication satellites, the Tracking and Data Relay Satellite System (TDRSS). These two satellites, which will greatly increase spacecraft communications capability, will provide coverage for spacecraft orbiting below 5,000 kilometers. Higher orbit satellites will be serviced by the reduced ground tracking stations. All data passing through the TDRS satellites will be collected at the NASA White Sands, New Mexico, facility where it will be formatted for high speed transmission to users for processing and distribution.

Our interferometry work continues with the development of the Mark-III Wideband Very Long Baseline Interferometry (VLBI) System which has centimeter accuracy. Measurements made in 1977 with our Mark-I system between the Haystack Observatory and Owens Valley, a baseline of 3900 kilometers, indicate about 3 centimeter accuracy. This is about one part in 10 to the 8th. We hope to do much better than this with the new system. The 3 centimeter measurement is the most precise transcontinental length measurement ever made. Transcontinental first order surveys using standard terrestrial surveying techniques are precise to one part in 10 to the 6th. Supporting our VLBI activity is of course our Goddard developed hydrogen masers which offer stabilities of parts in 10 to the 14th.

Oue new hydrogen masers which will be available shortly, will have stabilities of a few parts in 10 to the 15th. These masers will be under microprocessor control for remote monitoring of maser performance and remote control of maser operation such as automatic cavity tuning, synthesizer control, and zeeman frequency measurement. The new masers are transportable like our NP series but are more rugged and have longer battery life. The masers will be available for extensive testing during early 1979.

In support of all this scientific activity during the past twenty years has been the frequency and time community. Much of the scientific data that has been collected could not have been properly interpreted and correlated without precise frequency and time sources. Goddard personnel have, over the years, evaluated and used many techniques of time transfer including HF, VLF, dual VLF, radio navigation systems, portable clocks, television, and the use of satellites.

We are now looking to the future use of our own Tracking and Data Relay Satellites for submicrosecond timing of our Network and other facilities. During the mid 1980's, we also plan to make use of the Global Positioning System (GPS) for submicrosecond timing of our laser ranging network and special projects.

As our scientific programs have become more and more sophisticated, the development of precision frequency and time sources has kept pace. We have seen timing requirements increase from ten milliseconds worldwide during the Vanguard and Mercury flights of the late 1950's and early 60's to tens of microseconds in support of the Apollo program and scientific satellites, to today's microsecond requirements for laser ranging, scientific satellites, Space Shuttle and geodesy measurements. Goddard's timing requirements have increased about an order of magnitude per decade, and we foresee that during the 1980's and 90's the experimenters will need tens of nanoseconds timing which boggles the imagination. Likewise, frequency requirements have advanced from a few parts in 10 to the 8th in the 1950's to the present capability of parts in 10 to the 15th.

Only you people here today can possibly envision what will be required over the next twenty years and on into the 21st century. It is meetings such as this that stimulate the thoughts that bring forth the ideas that develop the systems of tomorrow. I encourage each of you to vigorously continue with your efforts. President Carter, in a message to the Nation last month, pointed out his desire that the United States play a prominent role in fostering space cooperation with other countries. It is meetings such as the PTTI that helps us expand our international activity. I welcome and encourage the participation by other nations in the PTTI.

I want to express my appreciation to the other organizations that cosponsor this meeting; Admiral Fowler and Admiral Smith from the Naval Electronic Systems Command; Captain Smith and Dr. Westerhout from the Naval Observatory; and Captain Heniffin and Dr. Berman our host from the Naval Research Laboratory. I thank you for this opportunity to speak with you this morning.

OPENING COMMENTS

RAdm. G. H. Smith
Vice Commander, Naval Electronic Systems Command

RADM. SMITH: Welcome to the Tenth Annual PTTI Meeting. It is a distinct pleasure for the Naval Electronic Systems Command to once again cosponsor this event.

There is a considerable concern within the Navy about the increasing number of systems requiring precise time and time interval. This concern unfortunately is not matched by an understanding of PTTI.

As an example, last spring there was a requirement to send a cesium clock to southern Europe to update the Verdin systems there. The standard we were sending, of course, required power on it more or less continually.

In order to keep power on the clock during the trip, arrangements were made with Pan American Airlines for the clock to travel first class. Unfortunately, one month earlier new guidance from the Secretary of the Navy put severe restrictions on first-class travel. If you weren't traveling in a stretcher or in a wheelchair or some other such thing as that, it was impossible to travel first class; and it certainly was not possible for an inanimate object to travel first class.

In trying to cope with this problem, we finally agreed that since we couldn't have a thing go first class, we had to at least make it appear that it was a person. So several messages were exchanged having to do with three people traveling first-class to Athens, Rome, and Naples. One of those persons was Mr. C. Clock. It seems that the only person that can give approval for this is the Secretary of Defense, personally. We spent more than two months trying to get approval.

Finally, I took a call from someone in OSD who said, "I don't understand what this is all about, anyway. Why don't you just listen to that Washington radio station and get one of those time checks?"

It is not surprising that you are not very well understood, because you are in the time business, and I challenge you to define time. You probably have argued about this among yourselves, time and time again; but about 40 years ago Albert Einstein defined time. Of course, time was very important to him, in those days. He defined time as "a succession of nows." But it is all relative, anyway.

For the past three years, we in the Navy have been trying to cope with our requirement for the future. We have finally come to grips with it; and it is very simple.

What we need, downstream, is a worldwide dissemination system, and a system on our platforms to distribute time throughout the ship. We don't need to go to picosecond timing in a foreseeable future. We need a way to cost-effectively get the time around. That is what we need.

It is true that our time requirements are becoming more stringent. But for the foreseeable future, they center on those time requirements which are governed by the Transit Improvement Program for navigation, and the GPS Navigational Satellite System; in the wildest stretch of the imagination, that is perhaps 10 nanoseconds.

We must also stop the proliferation of different types of clocks simply because we can't afford it. One solution might be to get a single, very reliable, type of clock that everybody can use. We haven't been able to do that.

We also frequently have a major problem setting our requirements. The first thing an engineer who has a system does, when he sets the requirements, is to look for what is available; when he gets the best he can find, that suddenly becomes the requirement.

Well, in the interest of time, I will make this short. You have three days of detailed technical sessions ahead of you. Please get the most out of the meeting and good luck to you. Thank you.

OPENING COMMENTS

Captain Joseph C. Smith

Superintendent, U. S. Naval Observatory

CAPT SMITH: Dr. Westerhout, Ladies, and Gentlemen: A little over one year ago I spoke at a symposium commemorating the discovery of the satellites of Mars by Asaph Hall of the Naval Observatory. During that talk I stated that I was convinced that there were still things to learn about our solar system, that it was evident that we did not know everything concerning the satellites of the planets nor did we necessarily know about the existence of all the satellites. Less than one year later, I had the honor to announce the discovery of a satellite of Pluto by one of our staff, Mr. James Christy.

While I do not claim yet to be a prophet I believe we can equally make predictions regarding the new and the unknown in the field of timing. Discoveries await which will be equally as exciting as what we have done in visual astronomy.

We are embarked now on a radio astrometric program utilizing the radio interferometer at Green Bank, West Virginia in collaboration with NRL, which promises not only a very precise means to determine UT and Polar Motion, but will also, I am convinced, shed new light on Quasar positions, Quasar physics, and a host of other areas. Our timing experiments in several areas with other individuals and organizations also offer promise for future development in timing as applied to navigation and communications.

Our efforts in time transfer are centered on two developments: A timing receiver for the GPS system, which will eventually allow much better timing world-wide; and the development and performance evaluation of mini portable clocks to cut costs of portable clock visits allowing more to be made. We have intensified our utilization and study of hydrogen masers as time keepers as well as other ways to meet the present and future requirements of the Navy, DoD, and other users.

Most people assume time as a matter of course, yet I am reminded each day of how important timing is to almost every aspect of our modern day Navy life. Electronic systems, navigation systems, communications systems, weapons systems, radar systems, missile systems, computer systems, and many others are going to be increasingly dependent on time. If our platforms of the future are going to be able to do their job, either singly or collectively, such as found in task force operations, a timing system is of the essence. I would like to reinforce Admiral Smith's comments regarding timing and distribution: It must be affordable, economic in operation and capable of world-wide use.

Thus, the challenge is there; there is much more we should know; there is much more we should do. This field is essentially a new one in regards to unprecedented precision and the scope of applications and involvement. There are many new frontiers waiting to be challenged. I am certain that this time next year we shall all be able to say: progress has been made. The amount of progress made rests with you. We of the Naval Observatory are both pleased and proud to be a part of this effort. With your help I am sure we shall be able to say we have kept pace with the clock.

I would like to put in a commercial at this time: For the correct U.S. Naval Observatory Master Clock Time you may call 254-4950, or AUTOVON 294-4950.

Have a good meeting. It is a pleasure for me to see you again.