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# PROCEEDINGS

# OF THE SIXTH ANNUAL

# PRECISE TIME AND TIME INTERVAL (PTTI) PLANNING MEETING

Held at U.S. Naval Research Laboratory
December 3-5, 1974

Sponsored by

U.S. Naval Electronic Systems Command
NASA Goddard Space Flight Center
U.S. Naval Observatory

Prepared by
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BANQUET SPEAKER

Dr. William T. Keeton
Langmuir Laboratory, Cornell University
Subject: The Continuing Mysteries of Pigeon Homing

CALL TO SESSION

James A. Cauffman, NAVELEX

WELCOME ADDRESS

Dr. Alan Berman, Director of Research, NRL

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The authors were responsible for the typing and proofing of all manuscripts. The Editorial Committee did not serve as referees but reviewed manuscripts only for gross errors.

# FOREWORD

This volume contains the papers presented at the Sixth 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 3-5, 1974 at the Naval Research Laboratory.

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. Thirty-one papers were presented at the meeting, covering areas of navigation, communications, applications of interferometry, frequency and time standards and synchronization, and radio wave propagation.

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 Sixth 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 1972, 1973, and 1974 Proceedings may be obtained for a charge of $5.00 by sending a request to:

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James A. Cauffman
General Chairman

# CALL TO SESSION

James A. Cauffman
Naval Electronic Systems Command

MR. CAUFFMAN: I am Jim Cauffman from the Naval Electronic Systems Command, and it is my pleasure to call to session the Sixth Annual PTTI Planning Meeting. I won't say too much about our program since it is pretty well laid out. It is tutorial in nature, and hopefully it will be of benefit to many people.

I believe that the Technical Program Committee, under Dr. Stover, did an excellent job in selecting the papers on the program. However, if anyone feels that certain topics are not adequately covered or that any other changes would be beneficial, please leave your suggestions at the reservation booth so that they can be considered for next year's meeting.

One of the most important benefits of this meeting is the gathering together of many knowledgeable and interested parties. Because of this, I urge all attendees to participate in the discussion period. To facilitate an accurate recording of the discussion period, we have a 5 x 7 card which you can use to write down your questions.

What we would like is the author's name, your name, and the title of the paper, and then the question. This will alleviate the problem we had last year of taking questions off the tape recorder and some people saying, "Gee, that is not really what I said."

These forms will be available at the microphones and should be turned in at the registration desk.

It is also important, I think 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, but also of different countries. Last year, six foreign countries were represented; this year, there are thirteen — Argentina, Australia, Brazil, Canada, Chile, France, Japan, Poland, South Africa, Switzerland, Taiwan, Thailand, and the United Kingdom.

I am sure this broadened international participation will be of great benefit.

It is now with great pleasure that I call upon Dr. Alan Berman, Director of Research of the Naval Research Laboratory for our welcoming address.

# WELCOME ADDRESS

Dr. Alan Berman, Director of Research
Naval Research Laboratory

DR. BERMAN: Good morning. As Director of Research in this laboratory, it is my pleasure to welcome you. I had the privilege of delivering a similar welcoming address approximately three years ago, the last time this group met here at the laboratory.

When one gives a welcoming address, it is usually one's habit to give some anecdotal material to sort of set the tone. And I recall at that time, I recounted the tale of an encounter I had with an Israeli General. He was, for those of you who weren't here, a very pragmatic, hard-headed person as are most Israeli Research Directors. In particular, he got to the point where he was teasing me about work in precision time and frequency. And he made some sort of remark because he was much taken at that time with the interest in tests of general relativity.

If I recall, about three years ago, people were flying cesium clocks around the world in different directions to try to test some of the twin paradox.

And he went on and on and berated me. And I tried to indicate the relevance and importance of precise time and frequency. And he kind of grudgingly conceded that it was worth doing, but in Israel, they don't measure the age of twins.

I met this gentleman some years later after the Arab-Israeli War, and he was very much sobered up. He actually apologized to me and said "Well, we still don't measure the age of twins, but we feel that the work in precise time, time standards, played an immense part in our military applications. We used it for TDOA, coding, navigation, cryptology, and one thing or another." He had finally seen the light and the value of much of the work.

It was sort of amusing to look at it, but I think that one doesn't need a war, and one doesn't need military applications to see the relevance of the sort of work you are doing.

Going through the program here and reviewing the work in the field over the past few years, I am indeed impressed by two things:

First, the broad, international participation in this meeting;

And second, the scope of your applications and interests.

Precise time, and time interval measurements have played a real role in the coming truly of age in the area of communications. Improvements in synchronization and time distribution technique I think arc allowing a wide variety of applications, both military and civilian.

We here at NRL are particularly proud and interested in the work of the Navigation Technology Satellite One. And it is very reassuring to us to think we have reached a point where you actually have rubidium clocks functioning in satellites and that we have programs, as you will hear, looking forward into the future to successively install cesium clocks and eventually a hydrogen maser before the end of this decade.

This will open up new frontiers, new abilities to determine time, transfer time, and achieve all the other things one can do.

Aside from the military aspects of what one can achieve with improved navigation, synchronization, cryptology, what have you, I am still enough of a scientist and have enough of a scientific background to be intrigued by the ability to tell the age of twins -- namely, one is intrigued by the possibilities that are opened with the availability of precise standards to test many aspects of the theory of relativity.

I am also extremely interested in the applications which I see you will be discussing in your program that are applied to geophysics and astronomy. You have the possibility now of observing crustal movements, possibly even using very long baseline interferometry to determine the possibility of earthquakes, severe tensions building up in continental margins or in continental crust.

I think the possible benefits of your work are only just beginning to become visible, and I look forward to seeing many more in the future.

Thank you, have a good meeting.

MR. CAUFFMAN: At this time, I would like to introduce the representative of our co-sponsor, NASA, Mr. Tecwyn Roberts, Director of the Networks Directorate, Goddard Space Flight Center.

## OPENING COMMENTS

Tecwyn Roberts, Director of Networks Directorate
Goddard Space Flight Center

MR. ROBERTS: Good morning, ladies and gentlemen. On behalf of the Goddard Space Flight Center, it is my pleasure to welcome you to the Sixth Annual Precise Time and Time Interval Planning Meeting. Goddard has been a co-sponsor of the PTTI meetings since 1972. It was our pleasure to host the '72 and the '73 meetings.

I am pleased that NRL is this year's host because it gives me the chance to visit this great facility which is known to us all. At Goddard, we have so many people who were at one time with NRL that I am not sure for whom they are still working.

The Goddard Space Flight Center is probably best known for its space programs in the fields of science and application. This was highlighted in this past year by the Atmospheric Explorer Satellite and the Applications Technology Satellite. The latter is playing a most exciting role in the area of communications testing and educational television on a global scale.

This, then, brings me to the part in which I am involved — the NASA Worldwide Tracking Satellite Network for which Goddard has the engineering and operational responsibility. In this area, we are indeed indebted to our friends at the Naval Observatory and the Naval Research Laboratory for many cooperative efforts. These run the gambit from cooperation in procurement of our new cesium standards for the NASA Network and visits to our tracking stations by Observatory personnel on their portable clock trips.

The network supports many spacecraft, civilian and DOD as well as foreign. These spacecraft have various missions, as I said, in support of scientific projects. Some of these projects impose stringent time and frequency requirements. Our present worldwide clock synchronization requirement is about 25 microseconds.

Upcoming projects will demand much better than this. The Geodetic Earth-Orbiting Satellite (GEOS) project will require about one microsecond at selected sites and frequency synchronization to a few parts in $10^{12}$.

The Earth and Ocean Physics Applications Program (EOPAP), the major goals of which are earthquake hazard assessment and global surveying and mapping, some of the things that Dr. Berman touched on, hopes to ultimately detect crustal motion to within one centimeter a year. To do this requires a station-to-station clock synchronization of better than one microsecond.

Our very long baseline interferometer program is multidisciplinary, providing continental drift, polar motion, and UT1 data to the geophysical community. Observations of the properties of quasars, pulsars and radio galaxies demand frequency stabilities approaching parts in $10^{15}$. This effort has drawn heavily on our in-house hydrogen maser development program.

I might add that we hope to track the NRL-developed TIMATION III spacecraft (NTS-1) with our laser tracking network for geodetic work. This is a stepping stone to the Goddard Laser Geodetic Orbiting Satellite Program, perhaps better known as LAGEOS.

We are continually evaluating new techniques to meet our time and frequency requirements. As I mentioned, we have an ongoing hydrogen maser development program. We are also investigating ways to improve our network timing for Loran-C, Omega, and Satellite Time Transfer.

Much of the PTTI work done at Goddard will be summarized in papers presented here during the next three days. So as you can see, Goddard is very much involved in the area of PTTI. It is through meetings such as this with the mutual exchange of information that enables Goddard to remain in the forefront of this very interesting and challenging field.

We look forward to continued cooperation with each of you in furthering PTTI capabilities. I thank you for the opportunity to greet you this morning, and I particularly thank Dr. Berman for permitting the PTTI meeting to be held here. I wish you a very successful three days.

MR. CAUFFMAN: Now, it is with great pleasure that I introduce my boss who will give us the opening address, Rear Admiral Raymond J. Schneider, Commander of the Naval Electronic Systems Command.

# OPENING ADDRESS

Rear Adm. Raymond J. Schneider, Commander
Naval Electronic Systems Command

REAR ADM. SCHNEIDER: Good morning, ladies and gentlemen. I have a few prepared remarks. I intend to slightly embellish them with some unprepared ones.

I particularly, as I look at the assembly, am somewhat envious of you in your scientific work. Deep in my heart, I always wanted to be a scientist. And I managed to approximate that by becoming an engineer, but it seems that in the military role, it is not very long after you become an engineer that you are a manager. And from then on, you spend all your time working in fields somewhat less rewarding than scientific or engineering personal performance.

Built on that little thought, I want to drive the community into a little bit of a challenge so that here today on behalf of my command which by its very nature is one of the more, I call it, exotic commands of the Navy, we have the strange capability of dealing with many complicated things that almost none of my peers understand. There is somewhat a tendency, rue the thought, of scorning me if I show some ability to understand. It seems to be unmilitary to know which end of a vacuum tube has the prongs on it.

I have always felt that way since I had my nose rubbed in this business. But I steel myself to believe that you can't hurt yourself by knowing what is going on. And so I insisted on understanding the business in my younger days. And it led to this fate I now pursue.

Let me welcome you then on behalf of the Navy's Electronic Command and the U.S. Navy itself to this Sixth Annual Meeting.

I want to also extend the welcome of the United States to the foreign visitors. We are very proud that you would take the time to come, some from Europe and South America and the Orient. We feel we have a mutual scientific interest here.

And I also note that no one else has remembered to notice that this grand laboratory has a Commanding Officer in the person of my good friend Captain John Geary. I want to thank him, along with Dr. Berman, for hosting our splendid meeting. He and his staff have made these facilities available.

I take particular pleasure in joining you who are somewhat experts in precise measurement of time in this scientific environment. These scientists here at NRL — and they are the laboratory, not the facilities — have put many new

scientific theories into operation, tested them, and evolved them into hardware. And remember hardware. Their fields of past renown have included radar communication, navigation, chromatic control, and some secret work that we still don't entirely talk about, and innumerable other disciplines.

The primary purpose of these precision time meetings is to exchange information, preferably scientific, although the social events may be interesting. In conferences such as this, the interchange and exchange of the technical information is probably immensely enhanced by the opportunity to have a face-to-face, eyeball encounter. I think this is most significant as we push against the frontiers here. I heard someone talking $10^{15}$. Heck, I am just as willing to talk $10^{24}$. Why set your goals low?

I had some of my physics acquaintances bumbling with the thought — and most physicists bumble quite a bit and stumble into results as much as they get them by deep scientific research. I wanted to know whether since everything else that seemed in our life in the ultimate appeared to have a quantum, there was a piece of below which you could get no smaller, I wanted to find out what the quantum of time was. Because it would seem to me that it would make some sense that since everything else has a quantum, why not time. You would finally get down to where there isn't a half of the one you got.

I was informed that, as usual, I didn't know what I was talking about. I haven't given up the thought. Man seems to be put together rather digitally if you really look into it seriously. And it is no wonder the Lord could walk through a wall, see. If you get your digits all lined up, there is one magic microsecond at which you could, indeed, synchronize and get through the wall. And you better do it fast.

And I hope that isn't blasphemous. It is just applying good scientific theory to the problem. You would be stuck forever if you blew it.

Anyway, our little meeting here is really about time — I am emphasizing the word "about." My speech writer is getting better. We realize that of the three fundamental quanities, and I think it is about time we took this very seriously, mass, length and time, the one most significant in the electronic scientific world has to be time.

Then being about right or about accurate is always very relative to what you are doing. Someone talks here that we can get around in milliseconds. Someone said a few microseconds. Well, you couldn't measure a loop mile with a radar, you realize, until you could measure something in the order of 12 microseconds more or less repeatedly, more or less all the time in any temperature condition. And we want to do a lot better than a loop mile.

But there are so many other places I want to do a lot better. As the state of the art in our electronics has advanced, the digital situation is simply overwhelming us. It is going to predominate. There is just no sense having analog voice radio, for example. It is passé. People look at me like I am crazy and still want to push the key.

But you can get so much more done digitally and still maintain voice recognition with a little effort that it is silly to consume the expensive rare band width with the beauties of an analog transmission. Now, once we get to that digital transmission and want to do it in all the circumstances that one might, military or civilian, one has to control the time. And the better you control time, the better your receiver works.

Finally, you end up not having to synchronize at all because you are always synchronized to some level of accuracy. We in the Navy have had a long history of being interested in scientific things. While I sometimes think our silver-plated badge of honor has tarnished somewhat over the last forty or fifty years, I personally belong to the clan that is doing everything it can to revive that place the U.S. Navy once held in the 1800's of being really the leader on the government side in scientific affairs.

And now we have a great partnership to share with the Bureau of Standards and the NASA and several other agencies that have come along and made important claims to the same situation and have not got a warfare role to nag them. Nonetheless, we, the Navy, are a scientific service. We can't operate to a great extent without our lowest-level officer being somewhat scientific and engineeringly inclined, to our detriment if we don't believe it.

We continue to press, therefore, in the study and development of time measurements and all instrumentation. My command assists the Naval Observatory as we execute our responsibilities in time management for the Department of Defense. NAVELEX with the assistance of NRL and the Observatory is itself the basic hardware management support for the entire operation. Our responsibilities have included engineering, procurement, calibration, planning, programming, budgeting, all those workhorse, housekeeping operations, to keep the research and development going and ultimately into the life-cycle support which is the tough part. It is the nagging part. Bits, pieces and part drugstore, I call it.

Our center here in Washington which is a field activity of mine has established depot repair facilities out at the Observatory to hang on to our clocks and keep them in calibration and repair. We have a test bed in Wahiawa — I give up; that one throws me all the time. It is in Hawaii. This site was selected because it was involved and closely proximate to various activities that might benefit from a time standard, and it was itself advantageous.

We are using this to determine operational requirements and help develop requirements, assisting in the implementation of the work you are doing, and create a frequency discipline of other facilities worldwide. We have had this thing running now for 18 months.

NRL here and under the sponsorship and working with NAVELEX has stabilized our VLF transmissions, making them coherent worldwide. Realizing the advantages of a VLF time and phase coherence, frequency shift keying coherence demodulator has been sponsored and developed. This unit at about $2,000 was able to hold up and be installed on operational submarines. So more now are going aboard and giving us a worldwide feasibility and operational test.

With this installation, substantially improved operational capability of the VLF broadcast reception then occurs in both Atlantic and Pacific. On one rare occasion when we did something right, we drew citations from fleet commanders who have cited both TELECOM, the C&O Managing Command, NAVELEX, the Material Support and NRL for this fine job.

In addition, shipboard time and frequency standards are now ready for operational evaluation. We plan to install aboard two tactical Naval ships, and this hopefully is the beginning of perhaps a program that is the mainstay of future fleet shipboard time and frequency distribution.

Looking a little further into the future, time sync and time transfer techniques, using the electronic system characteristics that are essentially fundamental to microwave satellite optical and wired technologies can be developed and easily put into place.

We must go on with processing clock systems for the program which are compact and versatile and can be matched for a specific use or extended to further applications. This processing of the clocks can be used either as a primary or secondary mode, comparison units, work in conjunction with atomic standards, time frequency oscillators, and of course now the maser. They would need to be designed to produce time of day, time of event, delayed time, time difference, coordinated universal time, any number of things. We can go on to infinity.

But you automatically, from the engineering point of view see the applications into the computer and information transfer world, the radio frequency oscillators which if they were accurate to $10^{15}$, everybody could sort of automatically navigate by inverse Loran with a tiny computer.

I spoke of this three years ago, and I feel rather futile in that I can't see anything happening. It moves so slow, so to some extent I chide you. Being scientific, I think you want to keep this racket going while you finish your career.

Now, that's why I said make it worthwhile. Let's go for $10^{24}$, and then you have got a longer future.

In the meantime, I would like to exhort some innovative individuals to get some of these things ever increasingly small while we on the one hand scientifically push for the best we can ever do, and that in itself is a goal, and that is a scientific goal. And I honor it. Ever increasingly better is the way we make progress.

Yet, there must be a spin-off from time to time. As I talked with Captain Geary for a moment over coffee this morning, it came to my mind if we sit around waiting for God to ordain that the PTTI program is great and should do many, many more things, we will wait a very long time. But if some of you great scientific geniuses, genii, will take ahold and back home at the ranch get something about the size of a shoe box or preferably a pack of cigarettes that will give me something approximately $10^{11}$ all the time or most all the time so that I can have it as the oscillator of my aircraft radio, for example, from which I build up the frequency synthesization, we begin to have some real application of the wonders of this art.

Indeed, the way to do it is not to announce loudly that you are going to have a PTTI oscillator; you just go do it and sneak it into the next radio. And when nobody is looking, you suddenly have a radio that is basically, by its own oscillator, a time standard. Once that starts to happen, we do the same thing in a computer, and we have a matched computer time standard, the same accuracy as the main oscillator of our radio. Pretty soon, we can talk in spread spectrum and all this sort of thing without this inordinate amount of effort in synchronizing and getting organized.

Now, I admit I don't know what I am talking about, and I don't know what I am dreaming about, but I have a sixth sense I am close to being right and close to being possible. It is my job nowadays to get on; my time is running out; I am getting old fast. I want to see some of these wonders installed in useful equipment

At any rate, let me finish here with the fine work added to it now, the long based interferometer, the things we have discovered there give us encouragement to believe it is really working, and we can go further.

For the future, we now stress having all our ship and shore facilities oriented to PTTI through applying the latest advances in the field of electronics to satisfy in a total system engineered complex. That is not as big a thought as some people think it is — to do everything right for a change in an organized way. Don't put the plumbing in the house after it is five years old. It is better to do it while building.

We can engineer these things in if we start.

I plan to see that my command puts forth its best efforts and provides strong support to this community, working with all their interested parties. Our particular role, of course, is hardware, and to bring the benefits of this expertise down to practical application on an everyday basis and across the ever-increasing number of electronic marvels where precise time actually dictates the speed of technological progress.

A lot of people don't understand that, but all of us here do. It is underlying the whole system.

So once again, now, I welcome you all, national and international visitors, for your participation in what I trust will be a most rewarding and successful meeting this week. Thank you.