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California Institute of Technology
Pasadena, California

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CONTENTS

OPENING ADDRESS

Twenty-five Years of PTTI

Gernot M. R. Winkler
U.S. Naval Observatory

SESSION I

Status of PTTI

Chairman: Richard L. Sydnor
Jet Propulsion Laboratory

DoD and Navy PTTI Report **11**
Richard E. Blumberg, Superintendent,
United States Naval Observatory

Status of Frequency and Time Support for NASA Systems **21**
Paul F. Kuhnle, Jet Propulsion Laboratory, Paul J. Kushmeider and
S. Clark Wardrip, AlliedSignal Technical Services Corporation

Time and Frequency Technology at NIST **33**
D. B. Sullivan, Time and Frequency Division, National Institute of
Standards and Technology

European PTTI Report **39**
Franco Cordara, Istituto Elettrotecnico Nazionale, Sabrina Grimaldi,
Politecnico di Torino, and Sigfrido Leschiutta, Politecnico di Torino

SESSION II

PTTI Management

Chairman: Ronald L. Beard
U.S. Naval Research Laboratory

WORKSHOPS

Three simultaneous in-depth moderator and audience discussions:

Workshop A – Ensemble Management **57**
Moderator: Sam Stein, Timing Solutions, Incorporated

Workshop B – User/Supplier Communication **59**
Moderator: Martin Bloch, Frequency Electronicsa, Incorporated

Workshop C – R&D/Sales/Engineering **61**
Moderator: Jack Kusters, Hewlett-Packard Company

An Operational Control Segment (OCS) Update on GPS Constellation Status and Future Program Directions **65**
Lieutenant Colonel Harrison C. Freer, United States Air Force, Falcon Air Force Base

LORAN-C Time Management **79**
Charles Justice, Lieutenant Norm Mason, and Commander Doug Taggart, United States Coast Guard, Radionavigation Division, USCG Headquarters

Report on NATO PTTI **93**
Dr. J. Bishop, Chairman NATO Working Group on PT&F, Ministry of Defense, London

SESSION III

Time Synchronization

Chairman: Claudine Thomas
Bureau International des Poids et Mesures

Two-Way Satellite Time Transfer: Overview and Recent Developments **101**
Gerrit de Jong, NMi Van Swinden Laboratorium

Optical Techniques for Time and Frequency Transfer **119**
Francoise Baumont and Jean Gaignebet, Observatoire de la Côte d'Azur

GPS Common-View Time Transfer **133**
W. Lewandowski, Bureau International des Poids et Mesures

Cascaded Clocks Measurement and Simulation Findings **149**
Don Chislow and George Zampetti, Telecom Solutions

Time and Position Accuracy Using Codeless GPS **169**
C. E. Dunn, D. C. Jefferson, S. M. Lichten, J. B. Thomas, Y. Vigue, and L. E. Young, Jet Propulsion Laboratory, California Institute of Technology

SESSION IVA

Applications I

Chairman: Henry F. Fliegel
The Aerospace Corporation

The Use of the AOA TTR-4P GPS Receiver in Operation at the BIPM for Real-Time Restitution of GPS Time **183**
Claudine Thomas, Bureau International des Poids et Mesures

Development of an Accurate Transmission Line Fault Locator Using the Global Positioning System Satellites **197**
Harry Lee, B. C. Hydro and Power Authority

Relativistic Theory for Picosecond Time Transfer in the Vicinity of the Earth 205
G. Petit and P. Wolf, Bureau International des Poids et Mesures, Queen Mary and Westfield College, School of Mathematical Sciences

A Real-Time Prediction of UTC 217
Claudine Thomas, Bureau International des Poids et Mesures and David W. Allan, Allan's TIME

Tropospheric Corrections to GPS Measurements Using Locally Measured Meteorological Parameters Compared With General Tropospheric Corrections 231
D. Kirchner and C. Lentz, Technical University Graz and H. Ressler, Space Research Institute

Accuracy Metrics for Judging Time Scale Algorithms 249
R. J. Douglas, J.-S. Boulanger, and C. Jacques, National Research Council of Canada

SESSION IVB

Poster Session

Chairman: Paul F. Kuhnle
Jet Propulsion Laboratory

Time Transfer Using Geostationary Satellites: Implementation of a Kalman Filter 267
F. Meyer, Observatoire de Besançon

The Two-Way Time Synchronization System via a Satellite Voice Channel 277
Zheng Heng-qiu, Zhang Ren-huan, and Hu Yong-hui, Shaanxi Astronomical Observatory

Remote Clocks Linked by a Fully Calibrated Two-Way Timing Link 285
James A. DeYoung, U.S. Naval Observatory and Ronald J. Andrukitis, U.S. Naval Observatory, Time Service Substation

A Comparison of GPS Broadcast and DMA Precise Ephemerides 293
Marc A Weiss, Time and Frequency Division, National Institute of Standards and Technology; Gerard Petit, Time Section, International Bureau of Weights and Mesures; and Steve Shattil, T Tauri Research

Some Applications of GPS Timing Information 307
Yinbai Zhang, Beijing Institute of Radio Metrology and Measurement

A Comparison of Several GPS Data Reduction Methods 317
H. Chadsey, U.S. Naval Observatory

Cesium and Rubidium Frequency Standards Status and Performance on the GPS Program 329
M. J. Van Melle, GPS NAVSTAR Operations, Rockwell Space and Operation Center, Falcon Air Force Base

Hydrogen Masers and Cesium Fountains at NRC **345**
J.-S. Boulanger, D. Morris, R. J. Douglas, and M.-C. Gagné, INMS, National Research Council

Comparison of LASSO and GPS Time Transfers **357**
W. Lewandowski and G. Petit, Bureau International des Poids et Mesures; F. Baumont, P. Fridelance, J. Gaignebet, P. Grüdler, and C. Veillet, Observatoire de la Côte d'Azur; J. Wiant, McDonald Observatory; and W. J. Klepczynski, United States Naval Observatory

LASSO Experiment: Intercalibrations of the LASSO Ranging Stations **367**
J. Gaignebet, J.-L. Hatat, J. F. Mangin, and J. M. Torre, Observatoire de la Côte d'Azur, W. Klepczynski and L. McCubbin, U.S. Naval Observatory, and J. Wiant and R. Ricklefs, McDonald Observatory

Noise and Drift Analysis of Non-Equally Spaced Timing Data **379**
F. Vernotte and G. Zalamansky, Observatoire de Besançon, and E. Lantz, Laboratoire d'Optique P. M. Duffieux, Facult des Sciences et des Techniques

An Algorithm for the Italian Atomic Time Scale **389**
F. Cordara, G. Vizio, P. Tavella, and V. Pettiti, Istituto Elettrotecnico Nazionale Galileo Ferraris

A Comparative Study of Clock Rate and Drift Estimation **401**
Lee A. Breakiron, U.S. Naval Observatory

Providing Hydrogen Maser Timing Stability to Orbiting VLBI Radio Telescope Observations by Post-Measurement Compensation of Linked Frequency Standard Imperfections **413**
James C. Springett, NeoComm Systems, Incorporated

Precision Frequency Synthesizing Sources With Excellent Time/Frequency Performances **425**
Liren Zhou and Hai Lin, Beijing Institute of Radio Metrology and Measurement

Time Maintenance System for the BMDO MSX Spacecraft **433**
Martin J. Hermes, Johns Hopkins University, Applied Physics Laboratory

Measurement of the Frequency Stability of Responders in Aircraft **445**
Xiaofan Liu, Beijing Institute of Radio Metrology and Measurement

Ground Control System for the Midcourse Space Experiment UTC Clock **457**
Richard Dragonette, Johns Hopkins University, Applied Physics Laboratory

Time Synchronized Video Systems **463**
Ron Burnett, ESE/SEKAI

Hydrogen Maser Clocks in Space for Solid-Earth Research and Time-Transfer Applications: Experiment Overview and Evaluation of Russian Miniature Sapphire Loaded Cavity **467**
G. Busca and L. G. Bernier, Observatoire de Neuchâtel (ON), Switzerland; P. Silvestrin and S. Feltham, European Space Agency (ESA); and B. A. Gaygerov and V. M. Tatarenkov, NPO VNIIFTRI

SESSION V

Applications II

Chairperson: Sheila Faulkner
U.S. Naval Observatory

Panel Discussions on Workshops: A, B, and C 481

Moderator: Ronald L. Beard
U.S. Naval Research Laboratory

Panel Members:

A. Ensemble Management

Sam Stein
Timing Solutions, Incorporated

B. Vendor/Customer Communication

Martin Bloch
Frequency Electronics, Incorporated

C. R&D/Engineering/Sales Communication

Jack Kusters
Hewlett-Packard Company

Ionospheric Corrections to Precise Time Transfer Using GPS 495
Robert W. Snow and Allen W. Osborne III, Allen Osborne Associates, Incorporated; John A. Klobuchar, Geophysics Directorate, Phillips Laboratory, Hanscom Air Force Base; and Patricia H. Doherty, Institute for Space Research, Boston College

The NIST Internet Time Service 505
Judah Levine, Joint Institute for Laboratory Astrophysics, National Institute of Standards and Technology, and University of Colorado

Reports on Other Conferences

Frequency Control Symposium 515
Jack Kusters, Hewlett-Packard Company

European Frequency and Time Form 517
L. G. Bernier, Observatoire de Neuchâtel

Institute of Navigation 519
Ronald L. Beard, U.S. Naval Research Laboratory

Civil GPS Service Interface Committee Meeting 520
David W. Allan, Allan's Time

Russian National Time Scale Long-Term Stability 523
N. B. Koshelyaevsky, A. P. Al'shina, B. A. Gaigerov, and S. B. Pushkin, NPO VNIIFTRI, The Institute of Metrology for Time and Space

Using GLONASS Signal for Clock Synchronization 533
Y. Gouzhva, A. Gevorkyan, P. Bogdanov, and V. Ovchinnikov, Russian Institute of Radionavigation and Time

SESSION VI

Next 25 Years

Chairman: Helmut Hellwig
U.S. Air Force Office of Scientific Research

A Look Into the Crystal Ball, the Next 25 Years 541
Helmut Hellwig, Air Force Office of Scientific Research, Bolling Air Force Base

Frequency Standards From Government Laboratories Over the Next 25 Years 549
Lute Maleki, Jet Propulsion Laboratory

Frequency Standards From Industry Over the Next Twenty Five Years 561
Leonard S. Cutler, Hewlett-Packard Laboratories

The Future of Time and Frequency Dissemination 573
Judah Levine, Time and Frequency Division, National Institute of Standards and Technology

TWENTY–FIVE YEARS OF PTTI

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Abstract

The availability of reliable, industrially produced atomic clocks in the mid–1960s brought about a great increase in the use of Precise Time and Time Interval (PTTI) in electronic systems, particularly in communications, electronic navigation, and space systems. By 1968, the need for better planning of timing operations, and also the need to inform systems managers and systems engineers of the capabilities of this new specialization became so great that a special Strategic Planning Meeting was organized at the U.S. Naval Observatory. The original purpose of the meeting, to plan, to exchange practical information, and to bring future requirements into the open, is still with us. The first meeting, in April 1969, demonstrated the need to make it into an annual affair. The talk will summarize the major developments that took place in the last 25 years and we will look back at the contributors and events that are now documented in the Proceedings. The discussion will also include some thoughts about suggested future directions in the organization of these PTTI Strategic Planning Conferences as they have now become a major feature in our timing community.

INTRODUCTION

The story of the 25 years of the PTTI conference can be told from different angles. First, I could review the achievements of the conference, and of its contributors. Then I should include a brief review of the main advances reported at this conference and acknowledge the work of those who made these advances possible; these people don't always show up at our meeting. We can also look with a more general perspective: Technical meetings such as this one are a major engine of scientific–technical progress. Without the pressure of deadlines, the great majority of the papers would not be published (that is my estimate, based upon my own experience). It is, therefore, of some importance whether and how these conferences are organized, who is the sponsor and organizer, and which goals will be pursued. And in the particular case of this PTTI Strategic Planning Meeting, these questions are probably even more critical than elsewhere if, as we hope, the information exchanged will influence decisions of often far–reaching importance. Therefore, questions of the management of conferences, particularly technical conferences, cannot be ignored because they are far more important than it may appear to the unsuspecting attendee. I want to take this opportunity to help clarify the peculiar aims of this conference, because knowing the goals should assist every participant to maximize the benefits arising from being here.

In this talk I will attempt to look at all of these aspects and my main motivation will be to do that in a way that will open up a vista of the future, as it can be seen today, of the conference as well as of the area of PTTI. We know, of course, that attempts to look into the future are notoriously deceptive. The expectation that things will continue in their present direction will almost always be disappointed because change is the most fundamental aspect of everything (and we should know because time is the abstract measure of change!). Indeed, the unforeseen is the most likely to happen. But by reflecting upon the driving forces of meetings and technology, and keeping in mind the general principles that govern all things, we could gain some idea of the potentialities of future developments.

BACKGROUND AND ORGANIZATION OF THE CONFERENCE

Looking back can indeed be salutary and humbling. When, in 1969, we decided to follow a recommendation made by Nick Acrivos[1] and Clark Wardrip (National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC)) to call a meeting as a forum to discuss what was really needed in the way of precise time and frequency, nobody dreamed about making this a regular conference, and it didn't appear at all likely that we would end up in splendid settings such as this one.

Unfortunately, Nick is not with us anymore. But Mr. Wardrip is here and we may question him as to what exactly they had in mind when they proposed a requirements and operations meeting at a time, when other people, such as myself, believed they knew exactly what the requirements for PTTI were. At any rate, the U.S. Naval Observatory (USNO) took up the suggestion, and the meeting turned out to be such a success that making it a regular event was one of the recommendations of that first meeting. The first meeting made it also clear that it was necessary to bring in more support by the way of additional sponsoring agencies concerned with applications of PTTI.

The reason for the success is, I believe, primarily due to two factors: There is a real need for a regular technical information exchange of this kind, and second, the conference management has kept the original goals and principles firmly in mind. Management! It has been often said, first by Lao–Tzu around 600 BC in the famous Tao–te–king, that the best government is the one that one does not see or feel. Because then, the people will say "We did it all ourselves!" However, a conference does not run by itself and definite visible actions are necessary; moreover, they must be planned far in advance. This is the function of an executive committee which is established by the sponsors. From the two original sponsors, NASA/GSFC and the USNO, the number has increased to seven. These sponsors, listed on the first page of the program[2], are those agencies that are most concerned with applications of PTTI, in operational systems and in R&D. Over the last 25 years, the interest and concern of various sponsors have changed and we have lost some of them, such as the National Institutes of Standards and Technology. This is regrettable, but we must understand the need everywhere to concentrate according to the local priorities.

The members of the executive committee, listed on page *ix*, are appointed by their respective

sponsor agency. They, in turn, elect a chairman. Most of the administrative functions are the responsibility of this chairman (Mrs. Sheila Faulkner, during the last 8 years), who must propose actions and get them approved by the committee. The overall policy for the conduct of the conference, therefore, comes from the sponsoring agencies through their respective representatives, and the committee meetings serve to coordinate these basic goals and to develop the details for the coming conference.

It is interesting to note that, in contrast to meetings organized by the various professional societies, the organization and the sponsors of this conference predominantly reflect management concerns. This is still a planning meeting and the objectives as listed on page *iii* reflect this very clearly. Our main concern is not in technical details but in making capabilities known, doing our best to avoid needless proliferation of efforts, revealing future requirements, and facilitating lines of technical communication. It is this fundamental difference in outlook and goals that sets this conference apart from other meetings. This difference is also reflected in the format of the Proceedings. Every effort is made to convey as much practical information as possible (names, telephone numbers, questions and answers, etc.)

It is only logical that in the light of this orientation, the whole organization of the conference has to be handled quite differently from what is the norm for purely scientific or engineering conferences. Ideally, we want to have the best compromise between technical expertise and presentation skills for our speakers, who are supposed to present overviews and ideas that will lead to discussion and further communication.

The experience of the last 25 conferences has shown that this lofty ideal is very hard to implement. Not only is it very difficult to find an acceptable compromise between the profound but incomprehensible expert on the one hand, and a showman who is only capable of producing platitudes peppered with an endless number of buzzwords, on the other, but in addition, there are the pressures coming from the "contributed" papers which we cannot, and should not, completely ignore. And there is an even deeper problem. It has to do with the art of maximizing useful information exchange in a very limited amount of time. As I see it, the presentations, in contrast to the more detailed papers, should only introduce a subject, delineate its scope, and give an idea of potential problems, but refrain from sticking with details. Now, please tell this to our esteemed colleagues! The real problem, in other words, is what Bohr called the unavoidable conflict between understandability and accuracy. But we must try! This is one of the heavy responsibilities of the program committee chairman. Again, a situation somewhat different from the usual situation where the major problem is usually to avoid getting papers which have been given already several times before. For us, if it is an excellent communication, that ought not to be a problem.

The second, and possibly an even more serious problem, is in attracting those people who can profit from the conference. We believe, with Socrates, that if one would only know what is best (in totality, i.e., in the long run), he could not avoid doing it! Hence, our most serious efforts to induce busy systems engineers and project managers to come here. I know that we have achieved an excellent features–to–price ratio, thanks to our executive committee chairman whose efforts are most appreciated. And, I believe, our efforts are paying off. In contrast to the general trend, the PTTI conference has increased its attendance, however slightly.

TECHNICAL PROGRESS AS SEEN AT THE PTTI MEETINGS

During these 25 years, we have seen the precision of timing go from about 0.1 microsecond to fractions of a nanosecond, and frequency control from parts in ten to the twelfth to parts in ten to the fifteenth. In the dissemination techniques we have seen our reliance go from VLF and Omega to LORAN C, and now to the GPS and two–way time transfers. Clock technology has seen an even more impressive change, largely due to the fantastic advance in electronics. There are three particular observations that I can make: the evolution of the hydrogen maser into the best available clock, albeit at a premium price and support effort; the perfection of the cesium standard into a most reliable, high accuracy, industrial product; and the very great effort that has gone into the GPS which has been the main driver for clock technology during the last 20 years. These are the most outstanding items, in my opinion. However, one must also mention a host of other developments. There is the impact of lower cost solid state electronics that has also achieved a previously impossible increase in reliability. And then we have the applications of PTTI in the most advanced research, in VLBI, in pulsar research and others.

During the first ten years of the conference, a tendency developed to focus very narrowly on particular systems during each year. One year we would see most presentations on LORAN C timing, in another it was VLF/Omega. Then it was hydrogen masers. This narrow selection was later abandoned in favor of a more general approach in the way this year's conference has stated its particular objectives on page *iii*.

In looking over the programs of the 25 years, it seems that the whole field has widened considerably. Two decades ago, no one was interested in timing of power systems, for example, or of timing via the Internet. We were much more narrow also in regard to the general technological approach. I believe this to be a sign of growing maturity of our specialty.

In looking back, I can also say that the meetings have been a major help for the USNO in its function under the DoD PTTI Directive. I also know that the Proceedings have been most useful to those who took the time to look through them.

OUTLOOK INTO THE FUTURE

With the caveats expressed at the beginnings of this talk, we can speculate about what is going to happen to this conference in the future. One thing is absolutely certain: It is not going to continue as it is today. And the change will come in a way that is hard to foresee now when the problems of today obscure our vision. I believe, however, that one can suspect a few tendencies. I expect a further increase in applications in mass electronics. In other words, while the main driving force of the past has been the desire for greater performance by way of accuracy, the future will demand lower price and smaller size as the main goals. Of course, this will depend very much on the general world political situation, no doubt. If a major economic crisis develops, then all technical activities will suffer. If, on the other hand, another major threat would appear, then we would see a resurgence of the hectic activities that will be necessary to defend us. At any rate, however, there will be no decrease of new ideas, of

inventions, of improvements of all kinds. It is only the rate of progress that is hard to gauge, not progress itself. And if the conference continues to be useful, then it will continue to report on these developments.

NOTES, AND LITERATURE REFERENCES

[1] Nick Acrivos, a retired Army major, had come to USNO from the Army Map Service as our first PTTI operations officer. His amazing energy and resourcefulness were major factors in the Observatory's quick implementation of the DoD PTTI Instruction. He coined the phrase Precise Time and Time Interval (PTTI).

[2] Program PTTI'93

QUESTIONS AND ANSWERS

M. Van Melle (Rockwell): I was wondering what the status of rubidium is. You didn't mention that too much.

Dr. Winkler: I have mentioned that as one of the technologies. If you look through the papers, the main emphasis during the last 20 years has been in the reduction of the drift of rubidium standards: a simplification in the manufacturing and reduction of the drift. In fact, the specifications very much emphasize a drift of less than, let's say, one part in ten to the eleventh per month.

I feel that this will not continue; that I can see the main applications of rubidium standards in the future where you don't care what the long-term drift is. But you want to have a reliable, small, cheap standard which can be within a few parts in ten to the twelfth, out to a thousand, two thousand seconds. Because, the main application will be in avionics, there's no question about that. And whether and how soon these applications will be translated into massive orders of tens of thousands of units depends entirely on the price. It is again this vicious circle that if things are too expensive, then no orders will come in; and if the price goes down then, of course, many, many more people will enter the market for it. Because, today the main application I can see for timing for the next two or three years will be in support of integrity monitoring, the range where you want to have an inertial and timing fly wheel which will carry you through 500 to 1000 seconds and allow you to reduce the dynamic problem to a stationary problem with integration, and so on. And then this, of course, requires that you have less expensive standards. So to come back to your question, yes there has been much emphasis. But I think for the future the emphasis will be different from what it has been in the past. It will be to reduce the price drastically and to relax the long-term stability requirements for rubidium standards.

Phillip Talley: I think it is important for this group to fully realize that rubidium has made significant advances in terms of stability and in terms of aging. And it will be the clock of the future for GPS on the II-R program. A lot of people may have been concerned that rubidium wouldn't have been as good as they had hoped for. But our demonstration is that it is as good and it is approaching certainly the performance of the cesiums and the predictability of aging is in there. I think that is an important thing for this group to understand.

Dr. Winkler: There is no question about that. On the basis of what we know today, I have to agree with you, even though I have expressed reservations about the II-R clock program in the past. In fact there are some rubidium standards in space now and have been all the time; except they have not been of the latest design or the latest type going in the GPS II-R program. Yes, I agree; but I consider that as a special, relatively small-scale application compared to

the masses of rubidium standards which I can see in the future to be used in avionics – and in other applications as well such as communications – where you do not need the long-term stability. In GPS, of course, that has been an absolutely indispensable requirement, that the drift be very small and that it be predictable. I would add to what you said, for short-term applications, its noise level is slightly better than the cesium standards. This is certainly true. But given the numbers – you are talking about 25, 30 satellites (or possibly a few more), compared to the tens of thousands of applications which I see coming. I wanted to make that point clear.

David Allan, Allan's Time: I would like to have your comments on two items if I may. First of all, it seems to me that as we look over the last 25 years, we see the development of techniques for characterizing the stochastic behavior of clocks. More recently, because of the larger number of applications, we have seen the need to be more careful about environmental characterization; there seems to be a trend. The IEEE specifically has issued a standard on the stochastic measures, and now we are working very hard to get a new standard which deals with environmental questions, I think because of the very important aspects of vibration and application-sensitive things. So that is item one.

The second item is that it seems to me that the large number of applications are coming in avionics, but I see a tremendous marriage occurring between telecommunication and time and frequency, which is going to be very important for the future for rubidium, quartz, cesium, hydrogen – perhaps not hydrogen in telecom; but I would like to have your feelings on that.

Dr. Winkler: I completely agree with both of your points, except that I did not spend time mentioning the standards which you have implied that exist and the effort on the part of the IEEE to come out with standards and recommendations in these areas. Because, I think this really has not been a major focus in this conference. The driving forces for these standards came more from the Frequency Control Symposium and most of it from the IEEE. That is the standards committee; and the international commission, CCIR, those are the drivers in that area. And the CCDS also, and the International Committee for Weight and Measures. So here, again, the emphasis is not in the development so much of technology as in the applications and, as you say education; bridging that gap of communication between two different cultures. That is what we are dealing with in this area. There are two different cultures: technology is on one side and managers, systems engineers on the other side. And that is a serious problem. And if we don't succeed in having some regular communication between them and mutual education, I think we will pay a dear price for that in the form of duplication of efforts, of wasted efforts of all kinds.

But I completely agree with your comment also that the communications area will see a massive application of atomic standards and of precise time and frequency technology in general. That is a sign of maturing technology, that suddenly a large-scale application comes up. And that will further cause a feedback loop, that by reducing the price of individual units, it will promote further increases.

John Vig, U.S. Army Research Labs: I think you mentioned that there is already a GPS receiver for $400; and it possibly can give you 100 ns of accuracy. I have two questions. How low can it go in the future? And, what will be its impact on PTTI as far as the business aspects

and as far as the research aspects are concerned?

Dr. Winkler: How low it can go – well, I think you have to start with the parts count, the necessary elements which have to go in. And I think $300 for a six–channel receiver OEM price is very low. I don't think you will see the price dropping much below that. I cannot see that.

But the second part of the question, what is the impact for science and technological applications, the answer is "vast." The fact that you can so inexpensively, anywhere on earth, have a common time and frequency reference has vast implications. Just yesterday I talked with John Klobuchar from Cambridge. He said that we have possibly hundreds of applications where we can time–tag remote measurements. We cannot do that now with sufficient accuracy. And economics come in very strongly too. So my answer to you very quickly is that the impact will be vast.

John Vig: That wasn't my question. The impact on the applications is going to be vast, no question about it. My question was, "What will it do to business by the manufacturers of PTTI products, people who make frequency standards for example?" Why do people need a two–thousand dollar oscillator if they can buy a four hundred dollar GPS receiver that can give them 100 ns? And why should the DoD, for example, sponsor research in this area on precision oscillators if people can buy a four hundred dollar GPS receiver?

Dr. Winkler: Your question goes to the very core of why do we use precision time and frequency standards in systems. We use them in order to provide a local independence for a certain period of time. I think that will continue to exist, that requirement. If you have an application which absolutey requires *at all times* to be within, let's say, one part in ten to the twelfth, I would not design a system without having a good cesium standard at that location.

So this will require very subtle judgments. And I think your question is a good one. It is certainly something which we have to discuss. And I am indeed aware of several problems which have cropped up in systems design where suddenly the budget people raised exactly that question: "If you have your time and frequency available, why do we need that?" That is a similar question of why do we spend money for insurance; it is exactly the same thing. It requires a risk analysis of putting numbers down, costs on it. My gut feeling is that you will always have to have some precision frequency standard. And certainly you will need good local oscillators.

Let's take the example, for instance, of GPS, the application. Why do we want to have a better standard in your receiver than what we use now? In order to facilitate a quick access, facilitate access during jamming, and all these questions. So the problem is much larger than just to say since I have time by buying a three hundred dollar receiver, I don't need anything else. Oh yes, you do if you are putting all these considerations into play. So my answer is that you still need it, but not in such massive numbers for such high precision standards as we do now.

Claudine Thomas, BIPM: You mentioned progress, in particularly hydrogen masers. Do you imagine that the definition of the SI unit for time, the second, could change in the near future?

Dr. Winkler: It is not, in my view, something which will happen during the next five

years. Because, there is no unanimity in regard to a possible practical replacement for the cesium definition. It is also certainly true – and I am sure our colleague, Don Sullivan and the gentlemen from NIST will agree with that – that we have not completely exploited the capabilities of the cesium standards for the provision of an absolute standard of time. I think there is still work to be done and is being done. And the advance work being done at the standard laboratories and research laboratories for an eventual replacement have not yielded a clear advantage in making a change here. It will take time. I think over the next five years, I do not see that any agreement can be reached to replace that and nor do I see that need for taht. But when it comes to ten years *and beyond,* based on what I said before, we cannot be certain that things will not be changed. But we have not yet any good candidate for that. Maybe Dr. Sullivan from NIST will want to make a comment to that regard.

Donald B. Sullivan, NIST: I agree, of course, with your conclusion. I would stretch that time frame out to 20 years even. The difficulty here is that you really have to demonstrate an overwhelming advantage before you change something like this. And the process of international standards agreement is a very cumbersome and time-consuming thing. We really don't want to see change occur too quickly because it can have a negative impact. I believe that the potential for cesium with not only the optical pump but also the fountains goes well beyond a part in ten to the fourteen, certainly to a part in ten to the fifteen; and I can't imagine right now the applications that will need that. So I don't really see a driving force for such a change.

Albert Kirk, JPL: I see this trend that we take the GPS system and steer primary and secondary house standards. To what are we steering to? Would you make some comments, please, on this chain of the GPS system? What exactly is NIST, USNO, BIPM steering to? Whose time are we synchronizing to? And what are the areas of uncertainty along this chain?

Dr. Winkler: There are two parts to the question. Number one, in respect to frequency, we steer in the long–run to the frequency as given by the BIPM, based on an average of laboratory standards. Whichever are available, these provide a long–term reference in frequency for the time scale. For GPS, that is being done via the reference which is steered very closely to the BIPM. And we will hear more about that later in the conference.

In respect to timing, you must have a generally accepted standard, which is UTC/BIPM. That is what they are steering on. If you look at the last year, the GPS has been kept within UTC very closely, usually within 100 ns RMS. And I think that will improve. So there is no ambiguity, we must have a general standard. Of course it is ambiguous to define originally UTC. What is UTC? UTC goes back to UT-2 on January 1, 1958. That is how the principal epoch was fixed. But from then on, we just kept time more and more accurately as we could in order to satisfy the divergent requirements coming from a common frequency reference to the divergent requirements coming from a time reference. The steering philosophy, all kinds of details enter here. We don't want to make epoch changes; we don't want to step unnecessary. It is enough to have the leap seconds, which will probably carry for a while with us, but we don't want to make unnecessary frequency changes. The long–term reference is UTC/BIPM, and that is what is being followed. And I think we are making increasing progress in doing that better and better as time goes on. Again we will hear more about that from Dr. Thomas later today.