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PRECISE TIME AND TIME INTERVAL (PTTI), AN OVERVIEW

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ABSTRACT

Present applications of precise time and frequency (T/F) technology can be grouped as follows:

1. Communications systems which require T/F for time division multiplexing and for using spread spectrum techniques.

2. Navigation systems which need T/F for position fixing using a timed signal.

3. Scientific-Metrological applications which use T/F as the most precisely reproducible standard of measurement.

4. Astronomical-Space applications which cover a variety of the most demanding applications such as pulsar research, Very Long Baseline Interferometry (VLBI) and laser/radar ranging. In particular, pulsar time-of-arrival measurements require submicrosecond precision over a period of one-half year referred to an extraterrestrial inertial system, and constitute the most stringent requirements for uniform timekeeping to date.

The standard T/F services which are available to satisfy such requirements are based on an international system of timekeeping coordinated by the Bureau International de l'Heure (BIH). The system utilizes the contributions from the major national services for standard frequency and time (USNO and NBS in the USA), and it is implemented through a variety of electonic systems (HF, T/F signals, VLF, Loran-C, etc.). The performance of these systems will be briefly reviewed. Several

of the user systems (such as VLBI) can, in turn, be used as contributors to the global effort of T/F distribution.

Moreover, PTTI is the one common interface of all time-ordered electronic systems. Time coordination (not necessarily synchronization) is the first necessary step for any wide scale integration and mutual backup of such systems.

OVERVIEW

In this short overview we can only mention the major aspects of time and frequency (T/F) which will be discussed extensively in the papers of the Proceedings. The main concepts are as follows:

1. Time of Day → UT1 (Rotation of Earth)
2. Clock Time at Standard Meridian → UTC
3. Synchronization
4. Accurate Frequency
5. Relativity: Local (Proper) Time, Coordinate Time
6. Coordination: 1 ms → 10 μs progress during the last 10 years.

For economical as well as practical reasons, SYNCHRONIZATION will usually be accomplished via clock time (UTC). Very accurate frequency cannot entirely be handled without also considering time. Relativity aspects must be considered if precision of better than a few hundred nanoseconds is involved. Lastly, the various international time services are coordinated with the BIH to the order of 10 μs - 100 times better than required by pertinent CCIR recommendations.

T/F has become a very active field during the last 10 years, due largely to the availability of commercial atomic clocks. Information is exchanged at a number of regular conferences, including the following:

1. Annual Frequency Control Symposium*, Atlantic City (U.S. Army), May.
2. CPEM, next meeting June 1976, Boulder (NBS-URSI-IEEE, Conference Proceedings in IEEE Trans. IM).
3. PTTI Planning Meeting*, Washington, December (annually), NASA-DoD.
4. URSI Commission 1 (National Meetings).

5. URSI Commission 1 (General Assembly (3 years), next in Lima, August 1975).
6. IAU, Commission 31, General Assembly (3 years) next Grenoble, August 1976.
7. International Congress for Chronometry* (5 years), last September 1974.

*Proceedings available

In addition there are regular training seminars by various groups, e.g., the NBS T/F seminars.

Let us consider the uses of T/F:

1. UT1 (mean solar or sidereal time) which is related to angular orientation of the Earth is needed for navigation, space tracking and geodesy. Essentially this application group is concerned with the orientation of the Earth in space and its rotation around its axis.

2. Other major uses deal directly with clock time. These applications come from a variety of time-ordered electronic systems:

a. Communications Technology

1) Time division multiplexing - channel packing, many stations on one frequency.
2) Reducing spread spectrum acquisition window.

b. Electronic Navigation in TOA Mode (Absolute)

1) For improved geometry of position determination (RHO-RHO).
2) For improved coverage - mixed systems.
3) For integration with communication and identification systems.

c. Metrology

Time and frequency are by far the best controllable parameters and can be used for measurement of length, voltage, pressure, temperature, etc.

d. Astronomy - Space Technology. This last application has the most stringent requirements - fractions of a microsecond over 1/2 year related to an inertial system (with relativity corrections for the movement of the Earth in the solar system).

These requirements for precise time are being satisfied in a variety of ways; with time signals, publications and superpositioning of the timing capability on existing electronic systems.

We have available the following time information services:

1. BIH Announcements.
2. U.S. Naval Observatory publications, particularly Time Service Announcements Series 1 through 17, and Almanacs (Ephemerides) (See Appendix).
3. National Bureau of Standards Time & Frequency Bulletins.

These services refer to time as it is disseminated by the following systems:

1. HF Standard T/F Signals: (WWV, CHU, etc.).
2. Timed electronic navigation signals: Loran-C, OMEGA, Transit, and later Global Position System (GPS), etc.
3. Wideband Communication links: Two-way.
4. Portable clocks, Precise Time Reference Stations (PTRS).
5. Special systems, largely under R&D: TV, etc.

The HF signals provide a global capability (including a great number of coordinated foreign services) of 1 ms precision, if propagation and receiver delays (3-5 ms depending mainly on band width used) are taken into account. Item 3 is potentially the most accurate, but portable clocks remain our final "authority" to calibrate services.

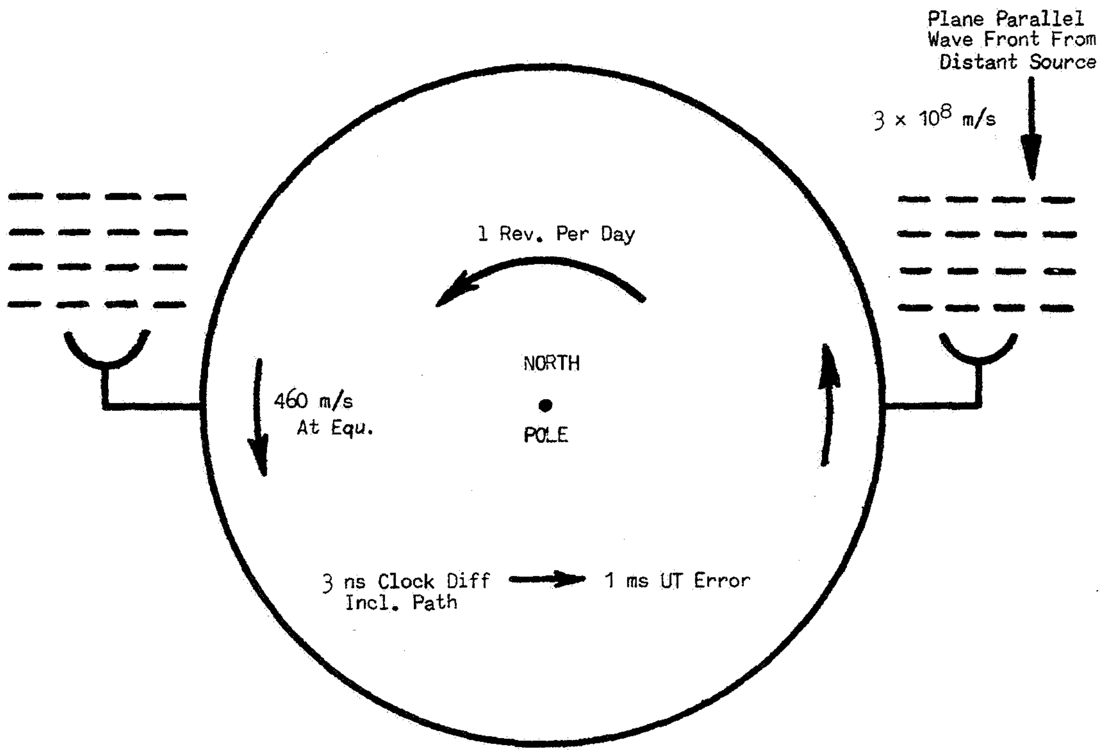
In greater detail, we could summarize the distribution capabilities as follows:

1. HF radio time signals:	1 ms global	
2. Portable clocks:	0.5 μs global	
3. VLF-OMEGA:	1-3 ms phase track (Relative)	
4. Loran-C/D	0.5 μs Northern Hemisphere	
5. Satellites:		
a. DSCS	0.1 μs "trunk line", global	2-way
b. TACSAT	0.5 μs "intermediate"	
c. TRANSIT	10 μs global	Silent (one way)
d. GPS	0.1 μs global	
6. Television:		
Local:	10 ns	
Long range:	1 μs	

7. Microwave, laser
   (local): 1 ns
8. Others: (R&D, VLBI, power lines, etc.)

As an example of users who can also help in global timekeeping, we can mention VLBI which, as the following sketch shows, provides both synchronization and UT (also the polar coordinates, x and y).

PRINCIPLE OF VLBI TIME DETERMINATION
UT1 VERSUS SYNCHRONIZATION
A USER AND CONTRIBUTOR



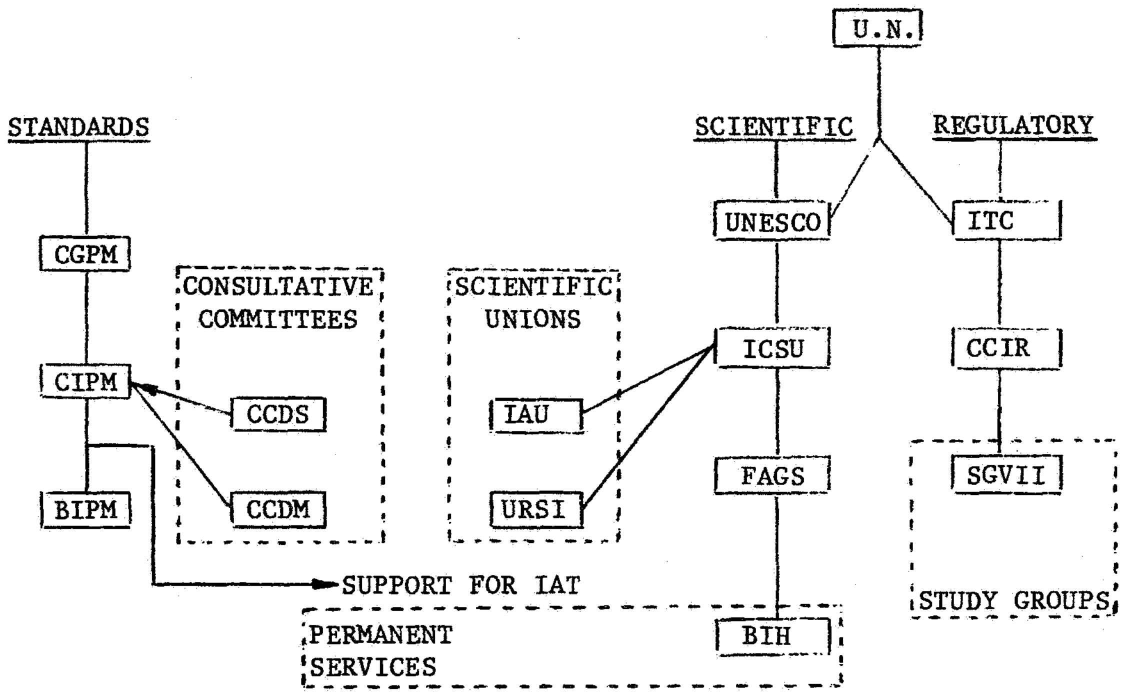
Redundant observations allow determination of time difference, base line, UT1 and polar coordinates.

Coordination of Services:

We have a system of international timekeeping in existence, coordinated by the BIH which is located at the Paris Observatory, and which is operated with some support from various international organizations.

The BIH operates under the auspices of the following organizations:

INTERNATIONAL ORGANIZATIONS INVOLVED WITH STANDARD FREQUENCY AND TIME



Abbreviations for PTTI

BIH - Bureau International de l'Heure
BIPM - International Bureau of Weights and Measures
CCDM - Consultative Committee for the Definition of the Meter
CCDS - Consultative Committee for the Definition of the Second
CGPM - General Conference of Weights and Measures
CIPM - International Committee for Weights and Measures
CCIR - International Radio Consultative Committee
IAT - International Atomic Time
FAGS - Federation of Astronomical and Geophysical Services
IAU - International Astronomical Union
ICSU - International Council of Scientific Unions
ITU - International Telecommunication Union
SGVII - Study Group 7
U.N. - United Nations

UNESCO - United Nations Education, Scientific and Cultural Organization
URSI - International Union of Radio Science

The national organizations (time services and/or standards laboratories) provide basic data to the BIH. The U.S. contributions from the U. S. Naval Observatory and the National Bureau of Standards are given in detail in NBS Technical Note 649, "The Standards of Time and Frequency in the USA".

In the United States, the division of responsibilities can be briefly summarized as follows:

T/F Responsibilities

NBS	USNO
National Standard of Frequency	National Standard of Time (Epoch, Date)
Standard Frequency (and time) Broadcast	Control of DoD T/F Transmissions
Fundamental Research in T/F as Related to Clock Time, Frequency Measurements	Applied Research in Time as Related to Clock Applications, Astronomy, Geophysics, and Navigation
Synchronization	Consultation and Management of PTTI Activities as Related to DoD
Consultation and Education	
PTRS for USNO	

The international clock time scales IAT and UTC are based on a number of individual clocks, presently operated by the following contributors:

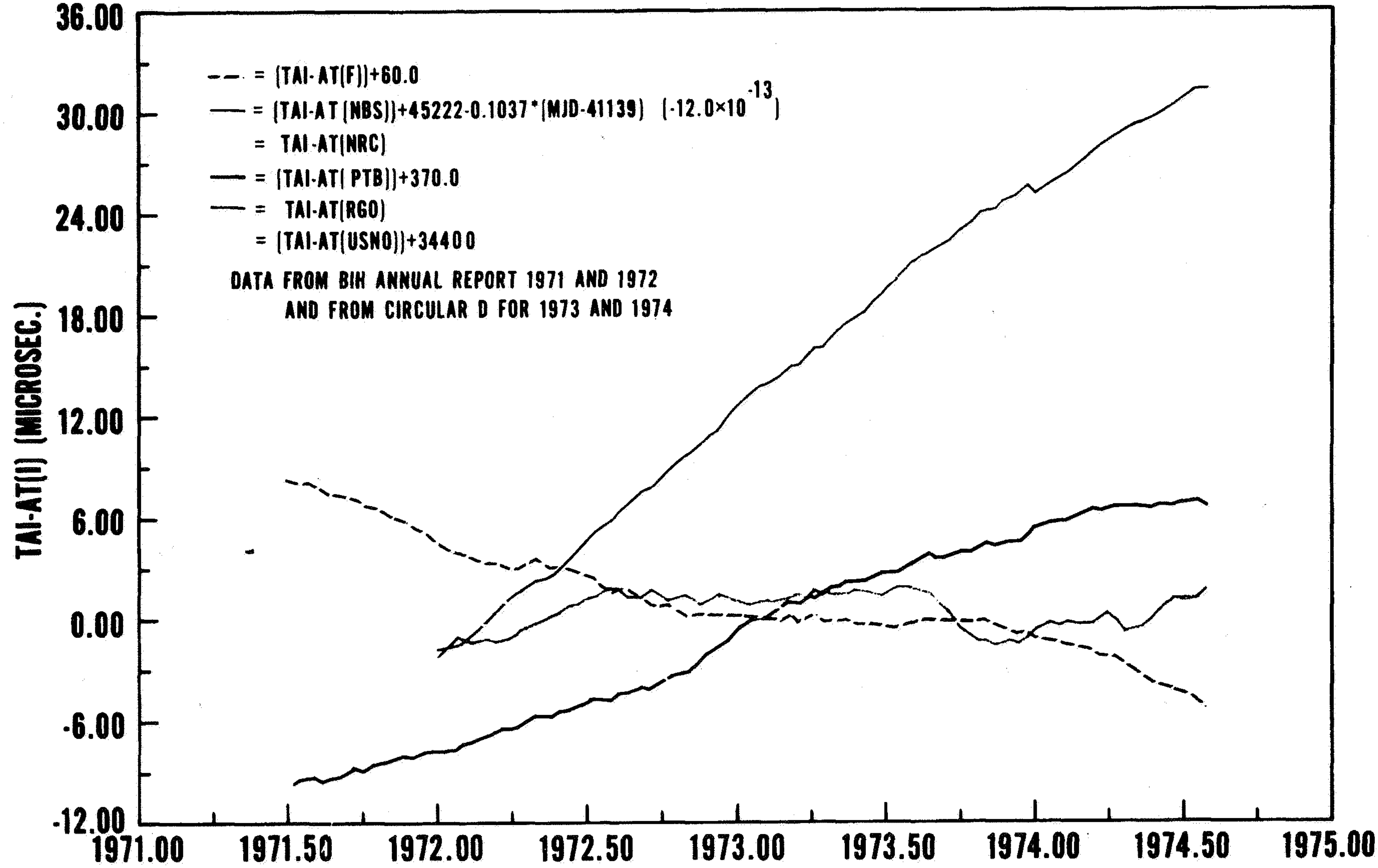
CONTRIBUTORS TO TAI (BIH)
(SOURCE BIH)

AGENCY	WEIGHT PER CLOCK	CLOCKS	TOTAL %	RANK
	%		%	
NPL	89	4	10	3
PTB	83	4	9	4
IEN	78	3	6.5	7
RGO	74	4	8.2	5
USNO	56	24	37	1
F	54	8	12	2
NBS	48	6	8.1	6
ON	44	4	5	8
NRC	37	3	3	9
ORB	26	1	0.7	10
TP	13	1	0.4	11
OMSF	3	2		
FOA	0	2		
PTCH	0	1		
VSL	0	1		

The table reflects the August 1974 situation. The Time Services in turn keep their coordinated scales for dissemination within about 10 μs of the BIH by making very small adjustments to their scales (10^{-13}). The clocks which contribute to the BIH are not adjusted.

The graph TAI - AT(i) depicts the performance of the internal scales of the major contributors as derived from BIH reports.

TAI-AT(I)


36.00
30.00
24.00
18.00
12.00
6.00
0.00
-6.00
-12.00
TAI-AT(I) (MICROSEC.)
1971.00
1971.50
1972.00
1972.50
1973.00
1973.50
1974.00
1974.50
1975.00
= (TAI-AT(F))+60.0
= (TAI-AT(NBS))+45222-0.1037*(MJD-41139) (-12.0×10^-13)
= TAI-AT(NRC)
= (TAI-AT(PTB))+370.0
= TAI-AT(RGO)
= (TAI-AT(USNO))+34400
DATA FROM BIH ANNUAL REPORT 1971 AND 1972
AND FROM CIRCULAR D FOR 1973 AND 1974

The results of the timing operations are published in bulletins which give actual clock differences. This is an example from Section 3 of the BIH Bulletin, Circular D92 dated 1974 July 4.

COORDINATED UNIVERSAL TIME

a. From Loran-C and Television pulses receptions

Date 1974		May 2	May 12	May 22
MJD		42 169	42 179	42 189
Laboratory i		UTC-UTC(i)	(unit : 1 μs)	
DHI	(Hamburg)	- 1.3	- 1.2	- 0.6
FOA	(Stockholm)	+ 38.5	+ 39.5	+ 40.1
IEN	(Torino)	- 10.5	- 11.0	- 10.9
NBS	(Boulder)	- 2.2	- 1.8	- 1.5
NPL	(Teddington)	- 36.4	- 36.8	- 37.1
NRC	(Ottawa)	- 0.6	- 0.5	- 0.1
OMSF	(San Fernando)	- 0.2	- 0.2	- 0.3
ON	(Neuchâtel)	+ 20.5	+ 20.3	+ 20.2
OP	(Paris)	+ 1.7	+ 1.9	+ 2.0
ORB	(Bruxelles)	- 33.5	- 32.3	- 31.8
PTB	(Braunschweig)	+ 0.3	+ 0.2	0.0
RGO	(Herstmonceux)	- 2.1	- 2.3	- 2.6
TP	(Praha)	- 25.4	- 25.6	- 26.5
USNO	(Washington) (USNO MC)	+ 0.3	+ 0.4	+ 0.5
VSL	(Den Haag)	+ 21.2	+ 23.1	+ 25.0

b. From clock transportations (unit : 1 μs)

From "Daily Phase Values", Series 4, No. 382, USNO

San Fernando Naval Observatory, San Fernando, Spain:
1974 May 16 (MJD = 42 183.3), UTC(USNO MC) - UTC(OMSF) = - 1.2 ± 0.1

CONCLUSION

PTTI technology offers capabilities which are desirable and useful in many modern electronic systems. With the availability of high performance atomic clocks (cesium beam, rubidium-gas cell and hydrogen-masers), the system designer can allow remote stations to operate with a high degree of independence (e.g. the VLBI receivers need no link, only initial synchronization).

As always, such extra benefits extract a premium price of additional complexity and training of operators. A standard timing interface (1 pulse per second, etc), with the large number of systems which are coordinated with UTC, allows some additional benefits and/or redundancy. One can therefore expect an expansion of the PTTI activities in the future.