PRECISE TIME DISSEMINATION VIA PORTABLE ATOMIC CLOCKS

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ABSTRACT

The most precise operational method of time dissemination over long distances presently available to the Precise Time and Time Interval (PTTI) community of users is by means of portable atomic clocks. The many attempts that have been made in the past to devise operational systems for submicrosecond time dissemination to supplant portable clocks largely have been unsuccessful. Many excellent techniques have been developed which are capable of the required precision. In some cases, the cost and burden of utilizing these techniques in a world-wide, operational time dissemination network have proved to be far greater than the portable clock costs. In other cases, the geographical coverage has been limited. In many cases, however, the managers of systems capable of being economically utilized for PTTI dissemination have been reluctant and, in some cases, adamantly opposed to even considering use of their systems for PTTI. In no case have the proposals for a system or a system modification solely for PTTI dissemination been seriously considered. The Global Positioning System (GPS) is the latest system showing promise of replacing portable clocks for global PTTI dissemination. Although GPS has the technical capability of providing superior world-wide dissemination, the question of present cost and future accessibility may require a continued reliance on portable clocks for a number of years. For these reasons it was felt that a discussion of portable clock operations as they are carried out today would be of some value. This paper describes the portable clock system that has been utilized by the U. S. Naval Observatory (NAVOBSY) in the global synchronization of clocks over the past 17 years, explains the concepts on which it is based and examines some of its capabilities and limitations.

INTRODUCTION

This paper provides a brief background description of the NAVOBSY portable clock service, including some historical information, and a description of the planning that is required, the hardware that is used, the services provided and the areas that are covered by regularly scheduled trips. The body of the paper concerns the acquisition, reduction, analysis and reporting of portable clock data and the procedures that must be used to insure the veracity of the data. Included are a discussion of the assumptions on which portable clock operations are based, the assignment of uncertainties to reported data and the process used in reducing data from trips. Finally some improvements that have been implemented and others that are under consideration for enhancing the quality of the service provided are presented.

BACKGROUND

Atomic clocks were first used in a "portable" sense by Reder and Winkler in experiments conducted in 1959 and 1960.[1] The clocks used were the early Atomichrons (Figure 1.), which were seven feet high and weighed several hundred pounds. They were portable only in the sense that they could be transported (with great difficulty) while running and required extensive support in the form of external power when being moved.

A significant reduction in the size of cesium beam frequency standards in the early sixties resulted in the design of a more compact, self contained clock (Figure 2.) that was truly portable in a practical sense in that two men could (with some difficulty) transport the clock to any location using readily available means of transportation. Its use was first demonstrated by Bagley and Cutler in 1964 and again by Baugh and Bodily in 1965.[2,3]

As a result of these demonstrations, a portable clock service was established by the NAVOBSY in 1965 in order to meet world-wide requirements for PTTI. Since that time, several thousand clock sychronizations have been done (Figure 3.). Figure 4 shows an early version of the portable clocks presently used by the portable clock service. This service has proved to be of immense value to U. S. Navy, Department of Defense, NASA and other national and international programs which require PTTI in their operations. It is one of the primary reasons why the many, widespread timekeeping activities that exist today maintain such a relatively high degree of synchronization.

Although a number of techniques have been demonstrated which allow time dissemination over fixed, long baselines to a precision as great or greater than can be achieved with portable clocks, there are no other operational systems which can routinely provide synchronizations to any spot on the globe. The only system with the demonstrated potential for surpassing portable clocks on a global, high availability basis is GPS. Unfortunately, the uncertainty of the future of the system and its accessability to non-Department of Defense PTTI users has had a significant, negative impact on the development of commercial GPS timing equipment.

PORTABLE CLOCK OPERATIONS

The effort required to plan and execute a portable clock trip is quite extensive and requires a coordinated effort on the part of a number of people and organizations to insure a reasonable probability of success. Although a tentative schedule is prepared over a year in advance of departure, detailed planning begins about thirty to forty days in advance when an itinerary (including cost estimates, planned activities and personnel assignments) is circulated to cognizant personnel for approval. Once this is completed, detailed planning begins in earnest as outlined in the standard operating procedures in Appendix I. In many cases, the itinerary has to be built around one or two key events which are outside the planner's control - Military Airlift Command (MAC) flights, foreign custom's assistance, local support at remote sites, etc. Throughout the entire planning and execution cycle, an attempt is made to strike a reasonable balance among the often conflicting requirements of the various parties involved - the best possible data from the scientific viewpoint, the most cost effective execution from the management viewpoint, and some reasonable travel conditions from the clock teams viewpoint. The first is the primary responsibility of the clock team leader and personnel in the NAVOBSY Time Service Data Reduction Branch. The second is the joint responsibility of the Precise Time Operations Officer, NAVOBSY management and the clock team. The third evolves from compromises worked out among all those involved in the process.

In addition to clock synchronizations, several other functions may be performed, depending on the requirements of the site visited. If valid requirements exist and are known and trip arrangements properly made to allow sufficient time on site, frequency offsets can be determined, clock adjustments made, maintenance performed, training given and any other PTTI related functions carried out. Unfortunately, in most instances, the pressing business of clock synchronization precludes spending any significant amount of time at sites other than those specifically identified in the itinerary. When requirements develop at sites near to those regularly serviced by NAVOBSY teams, little or no compensation is required from a qualified requestor. In cases where additional, significant cost and time are involved or the requestor is not qualified by virtue of being a U. S. government agency or contractor, the requestor is required to fund any additional expenses.

The NAVOBSY has several "standard" itineraries which are executed on a regular, yearly basis, many in cooperation with and supported by other agencies. A listing of these trips can be found in Table II. The itineraries are designed to cover the largest number of required sites in as short a time as possible without exceeding an approximate 21 day limit or overtaxing the clock team.

In order for the clock team to maximize the possibility of securing valid clock data, they must, as part of their pre-trip procedures, test the clock and any ancillary equipment required to support their efforts in the field. This involves testing and exercising the standby power system for the clock, testing the time interval counter to be carried on the trip, and assuring that the clock kit contains the connectors, adapters, cables, spare parts and tools that are necessary to assure continued operation of the clock throughout the trip. Thorough preparation, combined with adept, creative personnel, are vital if the team is going to overcome the unexpected events that are certain to occur in an undertaking of this kind.

DATA ACQUISITION AND RECORDING

The primary purpose of portable clock operations is to gather data which will allow the determination of a remote clock's time relative to that of an established time scale. In the case of the U.S. Naval Observatory clock operations, the time scale is Coordinated Universal Time (UTC) as generated and maintained by the Master Clock system in Washington, D.C.

The collection of portable clock data actually begins several days in advance of departure. As a matter of policy, atomic clocks designated for use as portable clocks are adjusted and kept as close in frequency to the Master Clock as possible and the time set such that the difference between the portable and Master Clock passes through zero at the midpoint of the trip. All operational NAVOBSY clocks are monitored continuously by an automated data acquisition system (DAS) in order to characterize their performance. A special effort is made to assure that clock performace data are taken for a period of five to ten days prior to and after the trip and that the data collection process is undisturbed over this period.

On the day of departure, clock measurements are made against the two reference clock systems in the Master Clock with both the permanent, high resolution (nanosecond or smaller) counter in the measurement console at NAVOBSY and the small, portable, ten nanosecond counter taken on the trip. A 1 PPS time tick to zero crossing of the 1 MHz signal from the portable clock is made on the portable counter to establish a reference value for use during the trip. All these data are recorded on a standard data form shown in Figure 5. Detailed measurement procedures and techniques employed in portable clock operations are not provided in this paper as the subject has been adequately covered previously.[4,5] However, some mention of the rationale behind them is warranted.

NAVOBSY portable clock operations are a significant undertaking. In 1980, for example, 302 clocks were synchronized during 120 site visits. This effort consumed 227 man-days of effort at a cost of over $95,000. These expenditures were those required to support clock teams while in the field and do not include initial equipment costs, pre and post trip data analysis, reduction and reporting costs, or the cost of supporting and planning the trips. Thus, the cost per clock synchronized is considerable, over $320 in 1980. It is imperative under these circumstances that procedures are used that yield consistant, unambiguous, correct data. Although the standard procedures employeed by the NAVOBSY in taking clock data appear rather simplistic, they are based on many years of field experience and are designed to minimize loss of data due to poor procedures. In order to be effective, the procedures had to be designed such that they could be carried out under the stressful conditions frequently encountered in portable clock travel. Many are obvious, common sense steps - use of a uniform set of cables, standard measurement parameters, a single set of measurement equipment, etc. Others - tick-to-phase measurements, measurement system reconfiguration to eliminate arithmetic and reduce number size, system designs to reduce measurement ambiguities, etc., are more subtle.

Clock data in the field are recorded on a data form which is prepared for each individual clock measured. Measurement of the primary clock at each site is required immediately on arrival, daily and prior to departure. Additional measurements on other clocks and timekeeping systems and measurements utilizing on-site equipment are made as required. As previously mentioned, depending on site requirements, equipment adjustments, maintenance, training or a variety of other functions may be performed. The primary responsibility of the clock team, however, is the acquisition and recording of valid clock data.

Regardless of the length of the clock trip, it must end with the same steps with which it began, comparison and evaluation against the NAVOBSY Master Clock. Once enough post-trip data are available to characterize the frequency offset of the portable clock, reduction and analysis of the trip data can be completed.

DATA REDUCTION AND ANALYSIS

One of the keys to successful portable clock operations is the proper reduction, interpretation and analysis of the data developed over the entire span of the trip, including the pre- and post-trip segments. In the past, when requirements were less stringent and capabilities more limited, a simple interpolation between trip end points was used to determine estimates of portable clock differences. However, increased requirements for higher precision time transfers necessitated improvement in portable clock data, particularly where perturbations in portable clock performance raised questions as to the accuracy of the resultant time transfers.

The pre- and post-trip portions are generally no problem as the data are readily available, stable, well defined and amenable to simple analysis. If the portable clock performs well during the pre-trip and post-trip segments, well defined, straight line fits can be made to the pre-trip and post-trip data. Extrapolation of these straight line fits through the trip period results in a single line defined by

$$y = mx + b,$$

where y = Master Clock - Portable Clock time differnce (usec),

x = Time elapsed (days),

m = Offset of Portable Clock from Master Clock (usec/day),

b = Constant defined by actual pre- and post-trip data (usec).

Ideally, the portable clock is set so that $m = 0$. Failing this, the clock is set so that $y = 0$ at the midpoint of the trip.

Figure 6 is a simple illustration of the concepts presented above. Figures 7 through 9 are several variations that can occur. In these illustrations the solid lines represent the pre- and post-trip comparisons of the portable clock against the Master Clock. The dashed lines are extrapolations of the pre- and post-trip clock performance data and the associated limits on the estimates of uncertainty which must be assigned to the data, given only the information on clock performance developed during those periods.

Figure 6 illustrates a best case condition where the portable clock performed exceptionally well and experienced no perturbations in operation during the trip. As a consequence, the uncertainty estimates are small and can be predicted with a high degree of confidence.

Figure 7 shows the result of an assumed, single, permanent change in the output frequency of the portable clock. Although a rigorous analysis of the situation might lead to a more refined performance model, this simple technique provides sufficient insight into performance with a minimum amount of effort. Propagating the uncertainties forward and back from the trip end points to a point of apparent discontinuity leads to an acceptable, conservative uncertainty estimate.

Figure 8 illustrates the result of an apparent step in time. In the absence of any additional information, one must assume a worst case condition where the discontinuity occurs at either end of the trip. Under these conditions, the extrapolation results in a large area of uncertainty which is compounded by the need to extend uncertainty estimates over the full length of the trip.

Figure 9 shows a situation where the liklihood of the occurrence of both a step in time and a change in frequency is high. Here again, in the absence of additional information on the performance of the portable clock during the trip, the uncertainty associated with the estimate of the portable clock values could be so high as to render the data worthless.

Under certain conditions the data from the last two cases sometimes can be salvaged. If portable clock measurements were made at a site whose clock had been recently synchronized by another portable clock or by satellite time transfer, or whose time is known to a relatively high precision at all times by virtue of it being a NAVOBSY Precise Time Reference Station (PTRS) or equivalent, then a point or several points can be determined at which the NAVOBSY - Site Clock difference is known to a better precision than that determined from the extrapolation process. The extrapolation and uncertainty determination are then adjusted to reflect this situation.

Thus, for any site clock measurement, M_i, made with the portable clock at time, x_i, during the trip, a post trip correction, y_i, is calculated and applied to the measured value to establish the difference, D_i, between the Master Clock and the measured clock, so that

$$D_i = M_i + y_i.$$

Associated with each measurement is an empirically determined estimate of uncertainty, u_i. The uncertainty consists of a fixed component which is associated with the measurement system and technique used, and a time dependent component or prediction uncertainty which increases with time, due to both the random and systematic performance characteristics of the portable clock. The uncertainty is at a minimum at the beginning and end points of the trip as the time dependent component is zero. In most cases, it is at a maximum at the midpoint of the trip, where the time dependent component is largest. In cases where a discontinuity occurs, the uncertainty is propagated over the entire trip. Additional information on these uncertainties can be found in references 5 and 6.

REPORTS

Dissemination of portable clock data is accomplished by several means and includes current trip schedules, future trip itineraries, and clock data from recent trips. All of this information is available electronically via the NAVOBSY Time Service Automated Data Service (ADS). The ADS consists of an extensive data base and the hardware and software to make it continuously available via telephone to any user with a compatible modem and computer terminal. A full description of the ADS is available from NAVOBSY on request.[7]

Individual clock reports are automatically prepared by a computer from the results of the reduction and analysis of all portable clock measurements made. After a multi-step review, these are mailed to the cognizant agency or personnel. An example of this report is shown in Figure 10. Those clocks that have significance with respect to international timekeeping activities receive additional scrutiny and additional certification is made (Figure 11). These results are published in the current Time Service Announcement, Series 4. In all cases, portable clock data go through several, distinct, independent levels of analysis and verification to assure the validity of what is published.

FUTURE IMPORVEMENTS

Improvements to portable clock operations can be viewed from two interrelated standpoints - cost and quality. As portable clock operations are manpower intensive, the only way to reduce recurring costs is to reduce the number of manhours required to acquire and process data while simultaneously maintaining or improving data quality. Trip lengths and itineraries have been examined and analyzed to the point where little else can be gained in this area without the risk of causing some degradation in overall operations and, specifically, in data quality. Two areas that offer some promise of success are (1) the reduction of the size of portable clock hardware to the point where one person clock trips would be possible and (2) the incorporation of more automation in the acquisition, reduction and analysis of clock data to reduce the time required for processing and to improve the data quality.

Information on a smaller clock and an improved, portable time interval counter for use in NAVOBSY operations was published in 1980.[8] The counter is presently used in all portable clock operations. The small clock has been successfully carried on several one and two person clock trips. It appears, however, that routine, one person clock trips on an operational basis will require further refinements in clock and power supply hardware.

A small, microprocessor-based measurement system for automatic acquisition and storage of portable clock data in the field appears feasible in the near future. Such a system would allow the automation of measurements, entry of clock identification and location information, back-up hard copy output of measurement data, and storage of measured data in a format and form that is suitable for direct, machine processing at the end of the trip. Further enhancements along these lines could include monitoring and determining the reserve capacity of the standby power system, measuring pertinent, ambient, environmental conditions and allowing the input and storage of flight parameters for use in evaluating clock performance over an entire trip. This would allow the implementation of routine correction for relativistic effects and provide the means of pinpointing perturbations in clock operations which currently cause serious problems in data reduction.

CONCLUSION

In spite of the fact that the NAVOBSY routinely maintains a widespread network of synchronized clocks utilizing a variety of PTTI dissemination systems other than portable clocks, portable clocks presently provide the only operational means of routinely synchronizing networks of clocks on a totally global basis. It appears that this situation will continue to exist for several years into the future. Improvements to both portable clock hardware and operation will be necessary in order to meet the current and upcoming requirements for synchronization.[9]

REFERENCES

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3. L.N. Bodily,"Correlating Time from Europe to Asia with Flying Clocks," Hewlett-Packard Journal, Vol. 16, No. 8 April, 1966.

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5. K. Putkovich, "High Precision Time Transfer Methods," Proc. of Seventh Annual PTTI Applications and Planning Meeting, December, 1975.

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8. K. Putkovich, "Time Dissemination - An Update," Proc. of the Eleventh Annual PTTI Applications and Planning Meeting, November, 1979.

9. Precise Time and Time Interval (PTTI) Program Improvement Plan, U.S. Naval Observatory Report, December, 1981.

Factor / System	Capability (μsec)	Cost ($K)	Coverage	User Skill	Daily Availability
				L-Low, M-Moderate, H-High	
HF Radio	1000	3	Limited Global	M	M
LORAN (Sky)	10-30	10	Limited	H	H
GOES	20	7	Limited	L	H
TRANSIT (NOVA)	10 (0.3)	10	Global	L	H
LORAN (Gnd)	1	10	Limited	H	H
LORAN (Auto)	1	10	Limited	H	H
TV Line 10	<0.1	5	Local	H	M
Portable Cs	<0.1	30	Global	M	L
GPS	<0.1	80	Global	L	H

Table 1. Operational PTTI Dissemination Systems

Table 2. Portable Clock Trip Schedule (FY 82)

OCTOBER	NOVEMBER	DECEMBER
FAR EAST	WEST COAST - 1	SO EUR
TOKYO, JA	SANTA CLARA, CA	NEA MARKI, GR
TAEGUE, KO	SUNNYVALE, CA	NAPLES, IT
TAEJON, KO	CP ROBERTS, CA	SAN VITO, IT
FT BUCKNER, OKI, JA	VANDENBER AFB, CA	TURINO, IT
HANZA, OKI, JA	PT MUGU, CA	MADRID, SP
WAHIAWA, HI	PASADENA, CA	SAN FERNANDO, SP
HAIKU, HI	WHITE SANDS, NM	LANDSTUHL, GE
BEIJING, CH	LAS CRUSES, NM	LONDON, UK
SHANGHAI, CH	SORRORO, NM	
XIAN, CH	BOULDER,CO	

JANUARY	FEBRUARY	MARCH
NE - 1		WEST COAST - 2
OTTAWA, CN		FLAGSTAFF, AZ
BOSTON, MA		YUMA, AZ
PROSPECT HARBOR, ME		SAN DIEGO, CA
COREA, ME		PT MUGU, CA
CUTLER, ME		VANDENBERG, CA
NEWARK, OH		SANTA CLARA, CA
IOWA CITY, IO		BOULDER, CO
MINN/ST PAUL, MN		LOS ANGELES, CA

APRIL	MAY	JUNE
CEN EUR		NO EUR
HAMBURG, GE		HOLY LOCH, UK
BRAUNSCHWEIG, GE		THURSO, UK
BERLIN, GE		EDZELL, UK
WETZEL, GE		AMSTERDAM, NE
GRAZ, AU		BRUSSELLS, BE
VIENNA, AU		PARIS, FR
NEUCHATEL, SW		LONDON, UK
GENEVA, SW		HERSTMONCEAU, UK
LONDON, UK		NEW DELHI, IN

JULY	AUGUST	SEPT
WEST COAST - 3	NE -2	SE USA/CUBA
SANTA CLARA, CA	OTTAWA, CN	MIAMI, FL
STOCKTON, CA	BOSTON, MA	KINGS BAY, GA
OSO, WA	PROSPECT HARBOR, ME	CHARLESTON, SC
SPOKANE, WA	COREA, ME	NORFOLK, VA
BOULDER, CO	CUTLER, ME	GUANTANAMO BAY, CUBA
CHEYENNE, WY	NEW PORT, RI	PATRICK AFB, FL
LA MOURE, ND	NEW LONDON, CN	
MINN/ST PAUL MN	FT MONMOUTH, NJ	

PC TRAVEL BY BENDIX

JAN	MAY	AUG
AUSTRALIA	AUSTRALIA	AUSTRALIA
SYDNEY	SYDNEY	SYDNEY
PERTH	PERTH	PERTH
YARRAGADGEE	YARRAGADGEE	YARRAGADGEE
CANBERRA	PHILLIPINES IS	KAWJALEIN IS
MELBOURNE	CLARK AB	HAWAII IS
ADELAIDE	SUBIC BAY	KAUIA
EXMOUTH	DIEGO GARCIA	MAUI
HAWAII	GUAM	LUALUALEI
WAHIAWA	HAWAII	HAIKU
	WAHIAWA	WAHIAWA

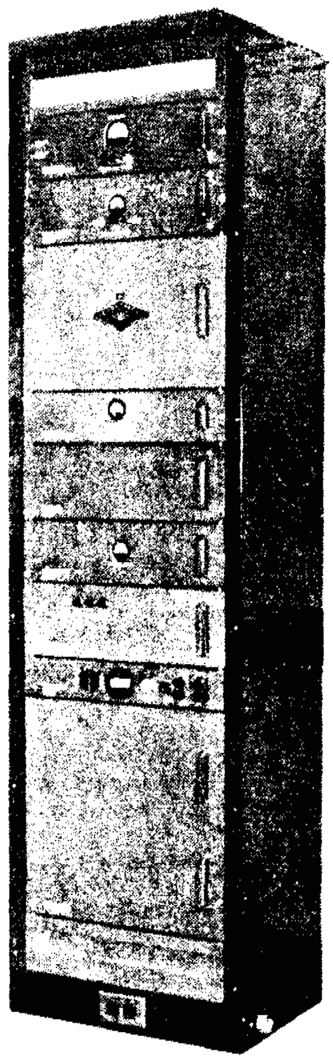

Figure 1. Atomichron "Portable" Clock (1959)

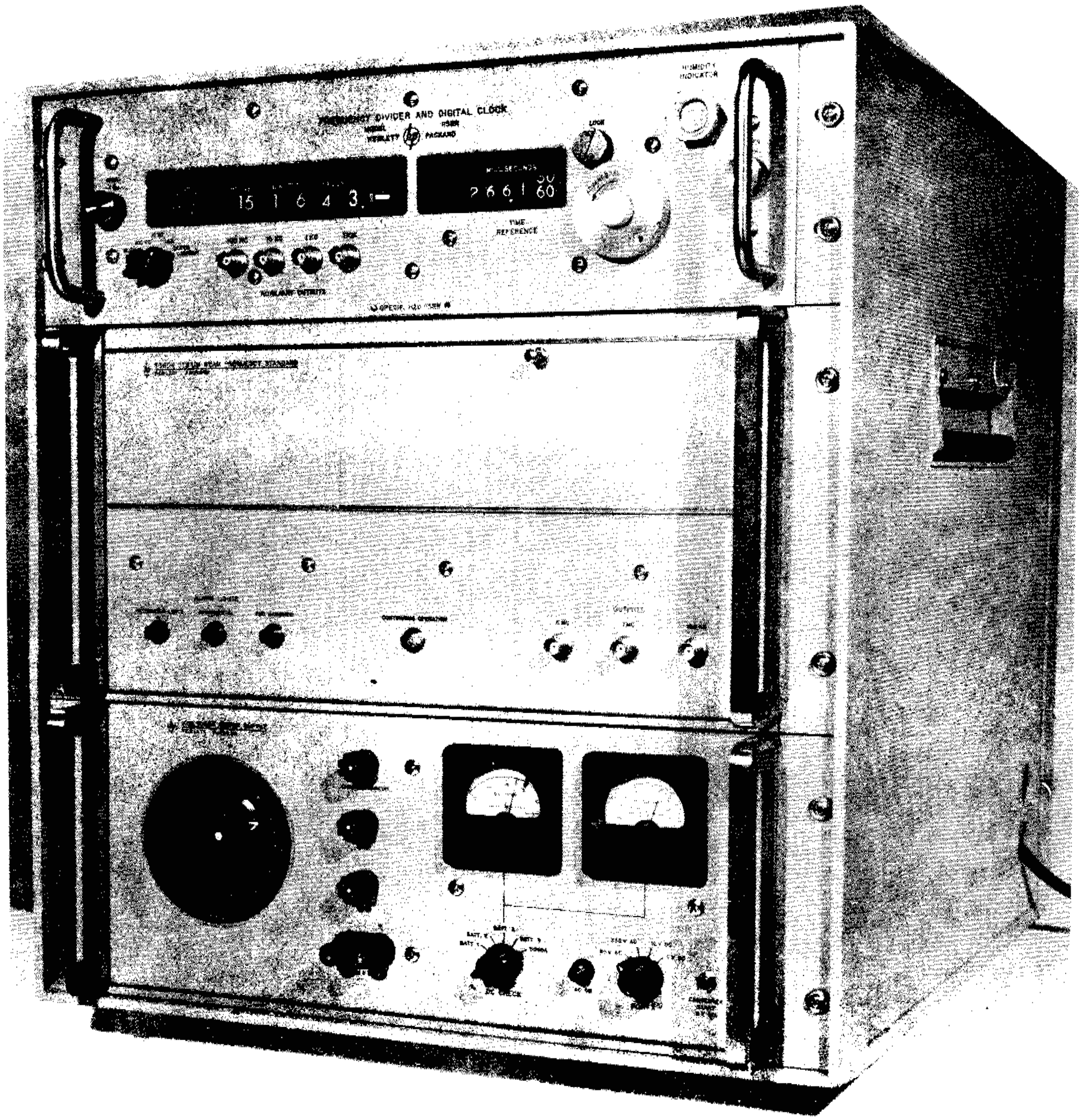

Figure 2. Hewlett-Packard Portable Clock (1964)

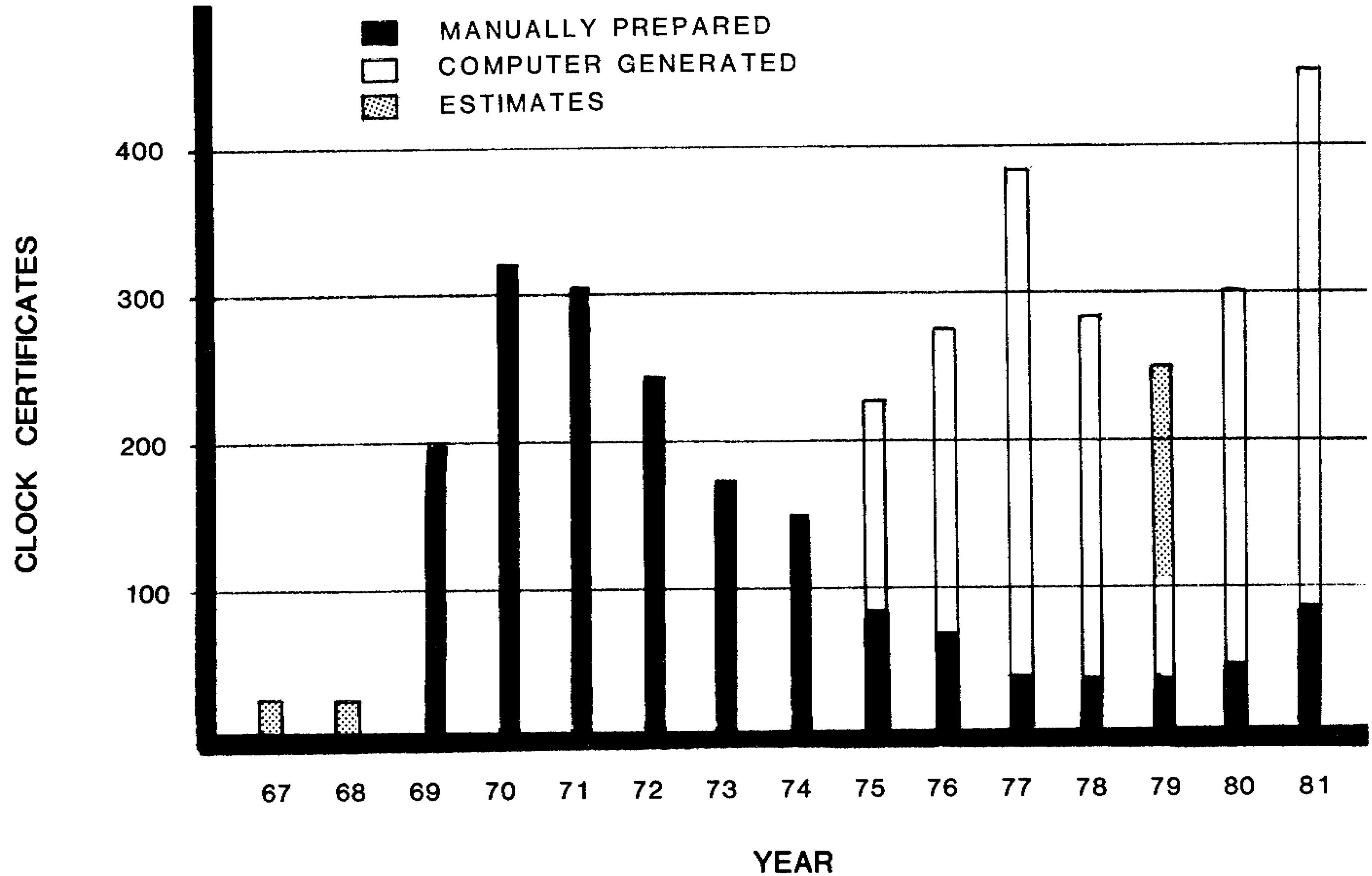

Figure 3. U. S. Naval Observatory Clock Certifications (1967-1981)

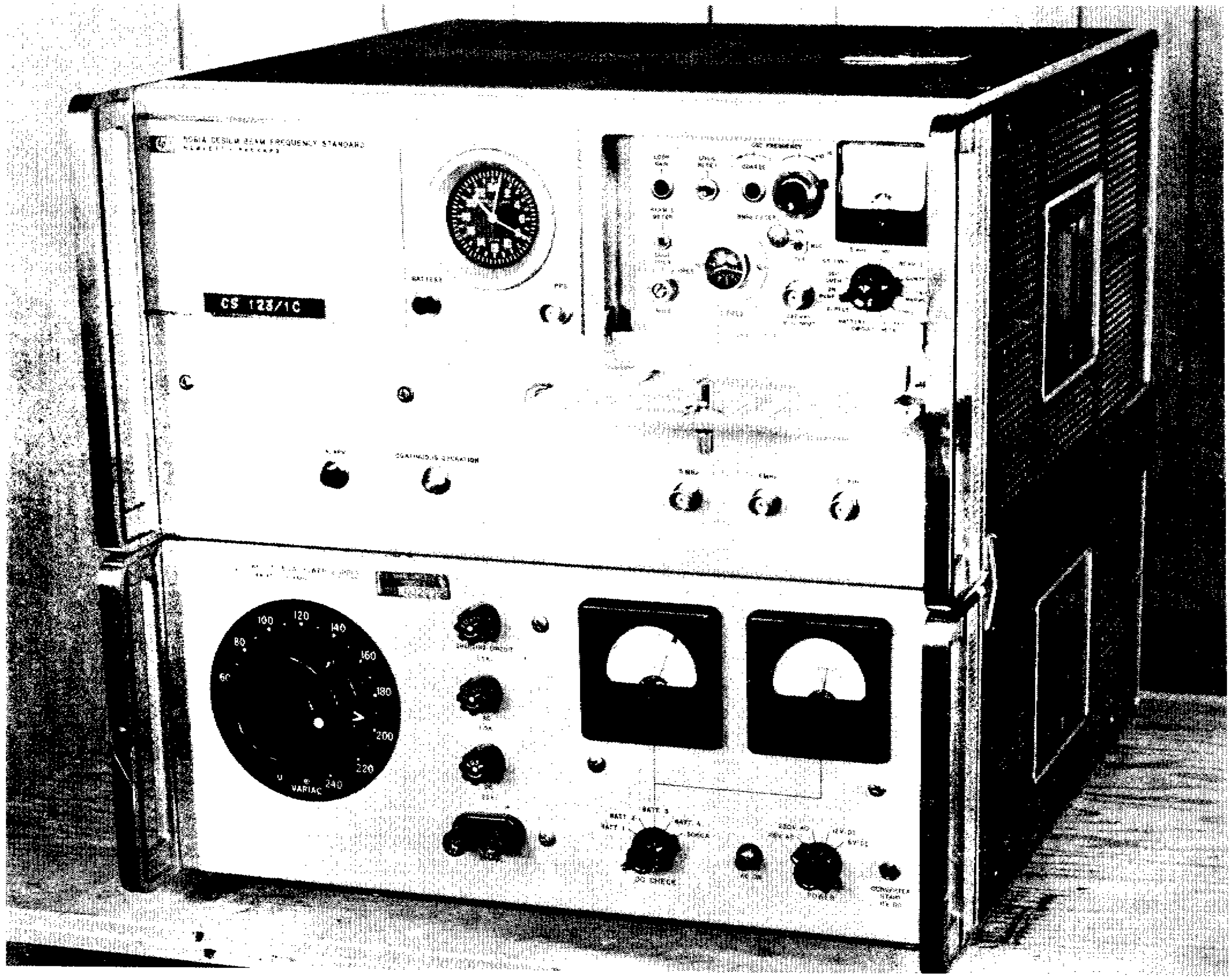

Figure 4. Hewlett-Packard Portable Clock (1968)

PTTI Form TS–1A

FIELD MEASUREMENT PTTI DATA SHEET

Activity & Location:	Personnel Making Measurement:

Time Standard		Measured Clock	Reference Clock
Clock Designation			
Osc.	Manufacturer		
	Model No.		
	Serial No.		
Clock	Manufacturer		
	Model No.		
1PPS	Polarity & Voltage		
	Slope		
	Input Impedance		

Time Display Agreement — Remarks

Hours ☐ Yes ☐ No ________

Minutes ☐ Yes ☐ No ________

Seconds ☐ Yes ☐ No

PORTABLE CLOCK TICK CHECK

(1 pps to 100 kHz crossover)

Positive-going 0 volt crossing ☐ Yes ☐ No

Day/Mon/Yr(ZULU) ________

Hours/Mins(ZULU) ________

PC – CS = ________ μsec

Calibration Certificate Mailing Addresses:

ORIGINAL TO:

____

____

____

COPIES TO:

____

1 PPS Sketch & Characteristics:

Amplitude: ________ volts, into ________ ohms

Polarity: ________ rise time ________ μsec

Pulse Length: ________ μsec

PTTI FIELD MEASUREMENT DATA

START CLOCK – STOP CLOCK	COUNTER READING + START DELAY – STOP DELAY = RESULTS (USEC)	DATE/TIME (UTC)
–	+ – =	
–	+ – =	
–	+ – =	
–	+ – =	
–	+ – =	

	THUMBWHEEL SETTING		"C" FIELD SETTING	
CLOCK	INITIAL	FINAL	INITIAL	FINAL

COMMENTS

Figure 5. Portable Clock Data Sheet

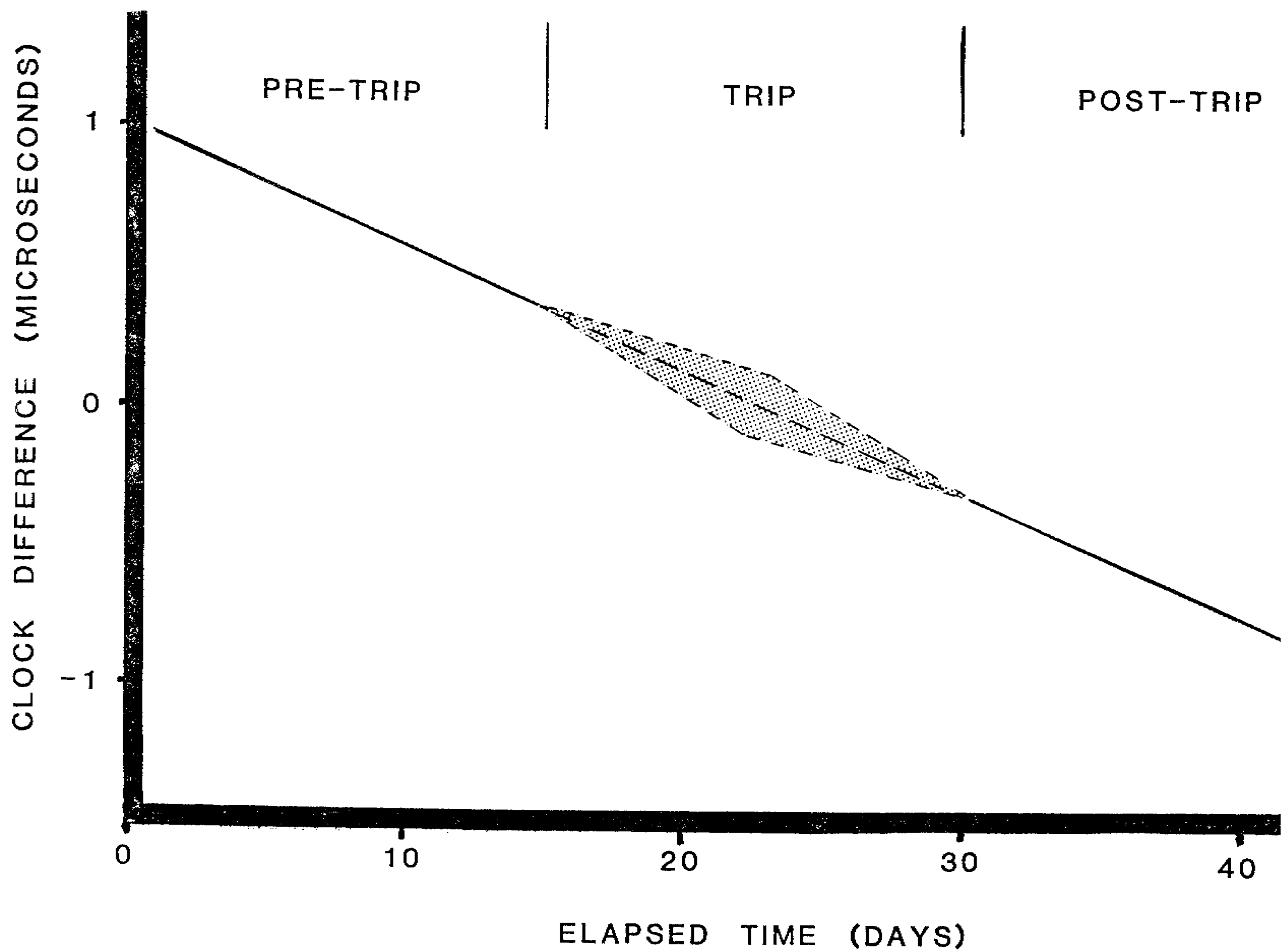

Figure 6. Portable Clock Performance (No Problem)

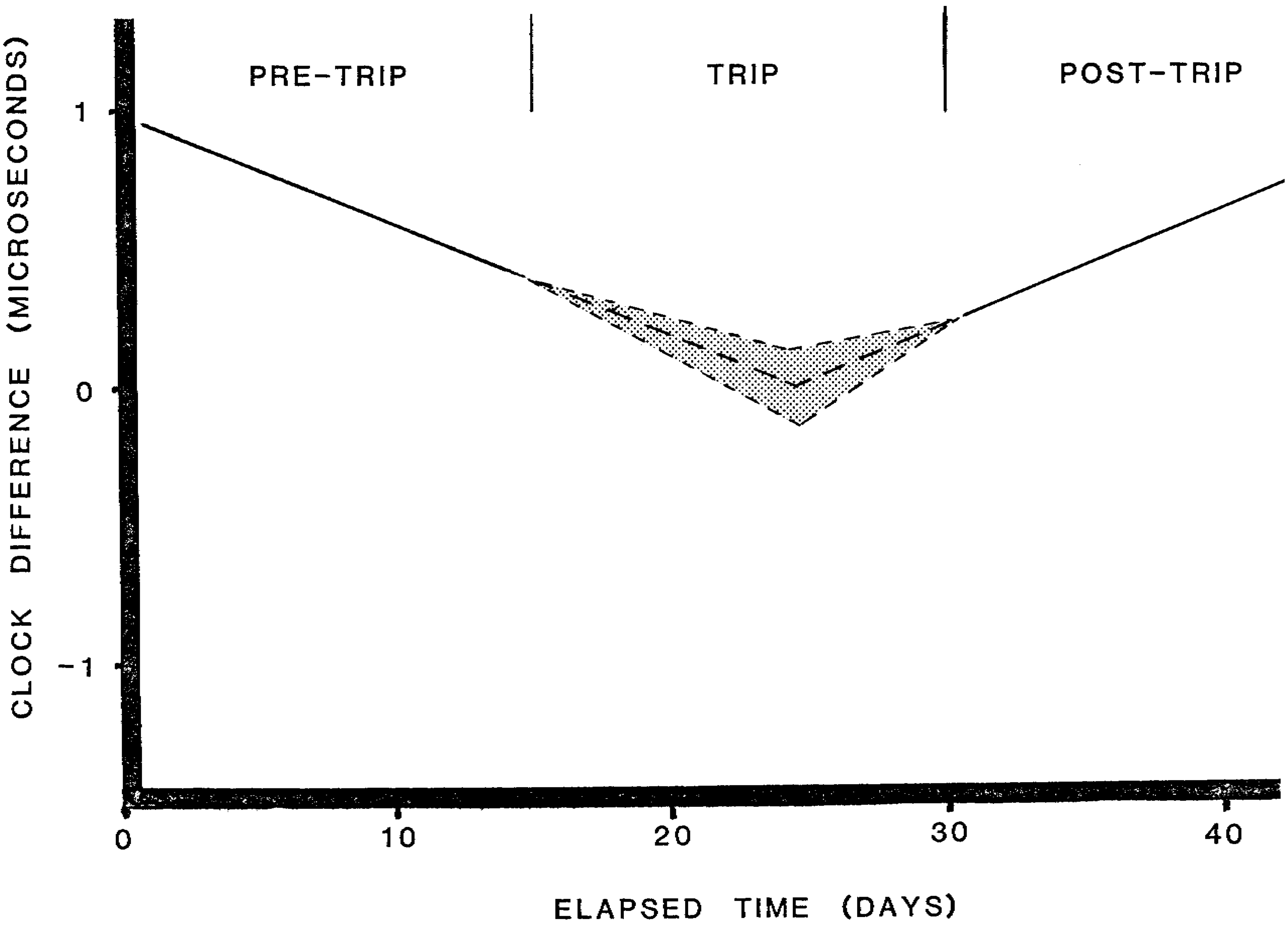

Figure 7. Portable Clock Performance (Frequency Shift)

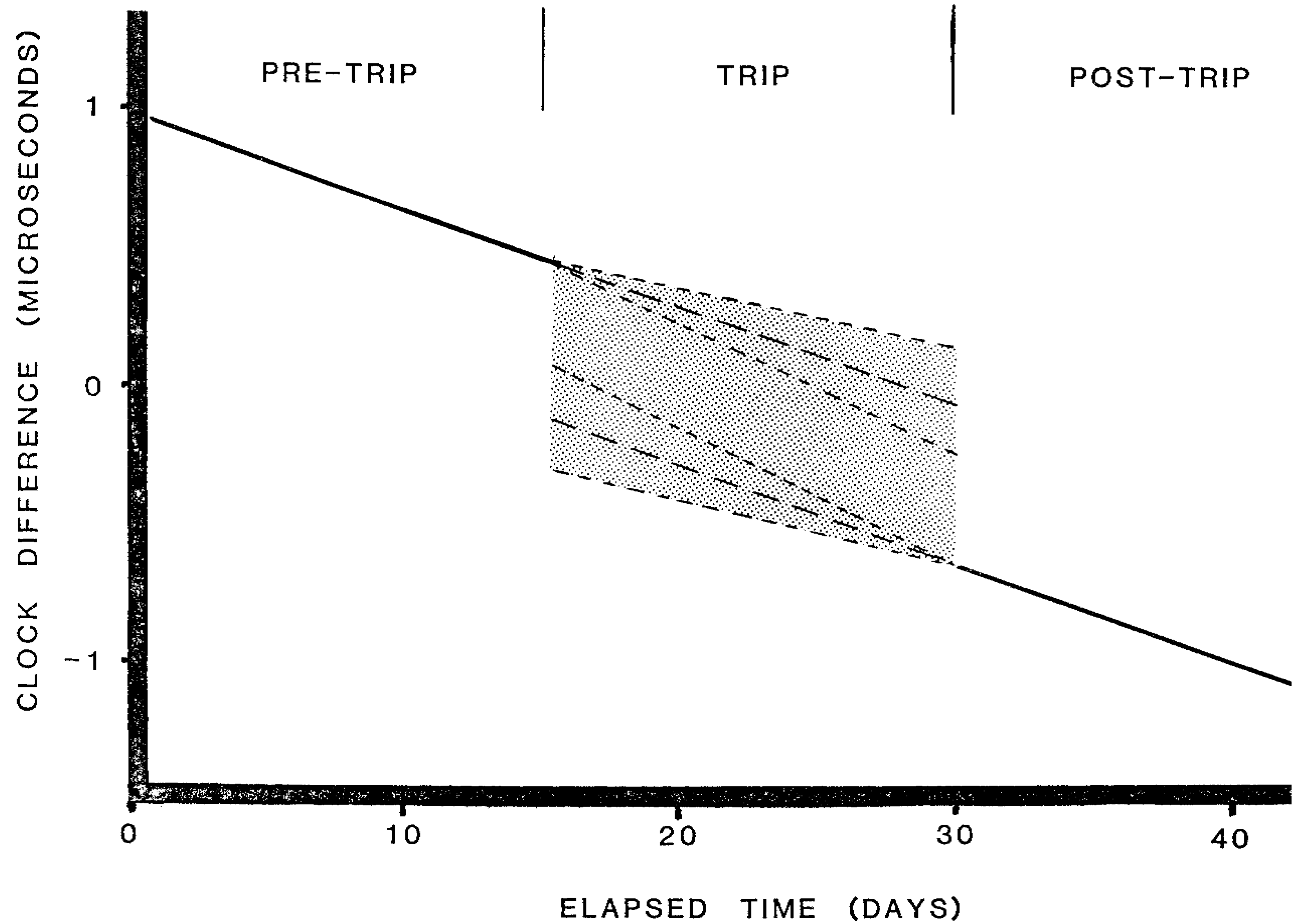

Figure 8. Portable Clock Performance (Time Step)

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

REPORT OF PRECISE TIME MEASUREMENT 1981 FEB. 1981

THE DESIGNATED CLOCK WAS MEASURED BY COMPARING ITS TIME OF DAY TO THE U. S. NAVAL OBSERVATORY MASTER CLOCK.

DESIGNATION AND LOCATION OF CLOCK MEASURED

CS651 COMSAT
GAITHERSBURG, MD

DATE AND TIME OF MEASUREMENT 1981 FEB. 13, 1853 UT, MJD 44648.786806

MEASUREMENT
UTC(USNO MC) - UTC(CS651) = 0.2 ± 0.2 MICROSECONDS

SPECIFICATIONS

TRANSFER TECHNIQUE UTC(PC1452)

ANDREW C. JOHNSON
PRECISE TIME OPERATIONS OFFICER

Figure 10. Computer Generated Clock Report

U.S. NAVAL OBSERVATORY
34th and Massachusetts Ave., NW
Washington, D.C. 20390

IN REPLY REFER TO

REPORT OF PRECISE CLOCK TIME MEASUREMENT

Designation of Clock Measured

UTC (NBS)

Location of Measurement

NBS, Boulder, CO

This clock was measured by comparing its time of day to the U. S. Naval Observatory Master Clock.

Date and Time of Measurement: 24 January 1973, 1818 UT, MJD 41,706.762500

Measurement: UTC(USNO MC) - UTC(NBS) = - 0.2 us ± 0.2 us

Specifications:

Transfer Technique: UTC(USNO PC 580)

Measured Clock Pulse Characteristics:

Amplitude = 1.3 volts into 50 ohms

Polarity = positive Rise Time: ~ 0.006

Pulse Measured At:

Amplitude: 1.0 volt Polarity: positive Slope: positive

Last Measurement Made Was:

UTC(USNO MC) - UTC(NBS) = 5.8 us ± 0.3 us

at 1510 UT on 11 May 1972

Date of This Report: 6 February 1973

By: JEAN D. LAVANCEAU
Section Chief
Control of Time and Time Interval
Time Service Division

Control No: A1169

Figure 11. Manually Prepared Clock Report

APPPENDIX I

STANDARD OPERATING PROCEDURES

FOR

PORTABLE CLOCK OPERATIONS

I. PRECISE TIME OPERATIONS SECTION

RESPONSIBLE FOR THE FOLLOWING:

1. INITIATE TRIP
   A. ITINERARY
   B. ESTIMATE COST OF TRIP

2. ASSIGNMENT OF PERSONNEL

3. CLEARANCE MESSAGES AND CORRESPONDENCE

4. PREPARE AND ALSO MONITOR TO ENSURE ALL DOCUMENTS ARE COMPLETED ON TIME.
   A. TRAVEL ORDERS
   B. TRAVEL ADVANCES
   C. TICKETS AND MTAS
   D. PASSPORT W/VISA UP TO DATE
   E. IMMUNIZATION RECORD UP TO DATE
   F. DATA FOLDER W/INFO SHEETS
   G. FIELD MEASUREMENT SHEETS
   H. CUSTOMS FORMS
   I. EQUIPMENT

5. PORTABLE CLOCK
   A. OFFSET
   B. ON TIME
   C. TEST

6. KO-2 POWER SUPPLY
   A. TEST

7. COUNTER
   A. TEST

8. TOOL BAG
   A. MULTIMETER
   B. CORRECT FUSES
   C. PROPER AC ADAPTERS FOR TRIP
   D. TOOL KIT
   E. AC EXTENSION (50')
   F. DC CABLE FOR CAR BATTERY
   G. FLASHLIGHT
   H. RAINCOAT

III. PRECISE TIME AND TIME INTERVAL BRANCH

RESPONSIBLE FOR THE FOLLOWING:

1. CHECK AND VERIFY ALL DATA AND REPORTS
2. PREPARE ADDITONAL CLOCK REPORTS AS NECESSARY
3. PUBLISH PERTINENT RESULTS IN TIME SERVICE SERIES 4
4. SEND CLOCK REPORTS TO COGNIZANT PERSONNEL

IV. PORTABLE CLOCK TEAM

TEAM LEADER HAS OVERALL RESPONSIBILITY AND THEREFORE SHOULD ENSURE TIMELY COMPLETION OF THE FOLLOWING:

1. DATA REDUCTION BRANCH
    - A. RATE OF CLOCK
        - 1. ADJUSTMENT IF REQUIRED
    - B. ESTIMATE PC AGAINST LORAN-C AND CESIUM AT SELECTED SITES
    - C. PROBLEMS WITH SITES THAT NEED TO BE INVESTIGATED
2. OPERATIONS GROUP
    - A. PASSPORT W/VISAS
    - B. IMMUNIZATIONS UP TO DATE
    - C. OBTAIN CLEARANCE MESSAGES AND CORRESPONDENCE
    - D. OBTAIN TRAVEL INFORMATION SHEETS AND PTTI FIELD MEASUREMENT DATA SHEETS
    - E. MONITOR PROGRESS OF DOCUMENTS
    - F. REVIEW CORRECT PROCEDURES
        - 1. MEASUREMENTS
        - 2. MESSAGES
3. CAR RENTALS
4. LIVING ACCOMMODATIONS

9. REVIEW CORRECT PROCEDURES
   A. MEASUREMENTS
   B. MESSAGES

10. ENSURE FOLLOWING IS OBTAINED FROM MS. CHARRON OR MR. CLARK
   A. PORTABLE CLOCK FREQUENCY OFFSET ESTIMATE
   B. PERFORMANCE ESTIMATE FOR PERIOD OF TRIP
   C. ESTIMATE READINGS OF PC AGAINST STATION CLOCKS AND LORAN-C AT SELECTED SITES

II. ASTRONOMICAL OBSERVATION AND DATA REDUCTION BRANCH

RESPONSIBLE FOR THE FOLLOWING:

1. ESTABLISH OFFSET OF CLOCK

2. ESTIMATE CLOCK PERFORMANCE FOR TRIP PERIOD

3. ESTIMATE PC AGAINST LORAN-C AND CESIUM AT SELECTED SITES

4. PROVIDE ABOVE INFORMATION BOTH TO OPERATIONS SECTION AND TEAM LEADER

5. ADVISE PC TEAM OF ANY PROBLEM AT SITES THAT NEED TO BE INVESTIGATED

6. ENSURE INPUT PORT FOR DATA ACQUISITION SYSTEM IS OPEN AND BEING SCANNED ON RETURN OF PORTABLE CLOCK TO NAVOBSY

7. ANALYZE AND REDUCE DATA AND PREPARE COMPUTER GENERATED CLOCK REPORTS

5. RECHECK
   A. OFFSET OF CLOCK
   B. POWER SUPPLY
   C. COUNTER

6. IF REQUIRED, TRAINING FOR ASSISTANT TO ENSURE HE/SHE IS ABLE TO TAKE READINGS AND HANDLE POWER REQUIREMENTS FOR PORTABLE CLOCK

7. TAG PC FOUR DAYS PRIOR TO DEPARTURE SO FINAL RATE CAN BE TAKEN---SAME HOLDS TRUE ON RETURN

V. FIELD OPERATIONS OF PORTABLE CLOCK TEAM

OPERATIONS AND RESPONSIBILITIES AS FOLLOWS:

1. DEPARTURE FROM USNO
   A. ENSURE DATA REDUCTION BRANCH RECEIVES COPY OF READINGS AGAINST SYSTEM 1,2, & 4
   B. START LOG ON CLOCK PERFORMANCE
      1. DAILY METER READINGS
      2. DAILY TICK TO PHASE
      3. TIME ON BATTERY VERSUS TIME ON CHARGE
      4. TEMPERATURE CHANGES
      5. ANY UNUSUAL PHYSICAL VIBRATIONS/SHOCKS
      6. ALARMS (INDICATE CONDITIONS, DATE AND TIME)
      7. LAST ENTRY SHOULD INCLUDE BOTH DEPARTURE READINGS AND READINGS UPON RETURN TO USNO (AGAINST SYS 1,2,4)

2. ALL MEASUREMENTS TO BE DONE AS FOLLOWS:
   A. TAKE READINGS AND ENTER ON DATA SHEET. INCLUDE ALL PERTINENT INFORMATION
   B. HAVE ABOVE RECHECKED BY ASSISTANT
   C. READ "C-FIELD" AND WHERE POSSIBLE THUMBWHEEL SETTINGS

3. UPON ARRIVAL AT SITES, CARRY OUT THE FOLLOWING:
   A. OBTAIN INFORMATION ON POWER AVAILABLE
      1. ENSURE POWER/VOLTAGE SETTINGS ON BOTH POWER SUPPLY AND COUNTER ARE CORRECT

2. IF EQUIPMENT MUST REMAIN OVER-NIGHT, EXPLAIN OPERATION OF BOTH POWER SUPPLY AND CESIUM OSCILLATOR, INCLUDING ALARM CONDITIONS. LEAVE WRITTEN INSTRUCTION SHEET WITH PLACE OF LODGING AND PHONE NUMBERS. REVISIT SITE BEFORE TURNING IN IF POSSIBLE

4. TAKE READINGS PER INSTRUCTION FOUND IN NAVOBSY TS/PTTI SOP-81, 6-1 PORTABLE CLOCK OPERATIONS

5. ASSISTANT IS TO VERIFY AND CORRECT, OR FILL OUT NEW TRAVEL INFORMATION SHEET

6. WHERE POSSIBLE, MESSAGES SHOULD BE SENT BACK TO INCLUDE:
   A. READINGS
   B. QUESTIONS PC TEAM WERE UNABLE TO ANSWER
   C. CHANGES IN THUMBWHEEL/C-FIELD SETTINGS
   D. OVERTIME/COMPTIME

7. AT SELECTED SITES INSURE READINGS ARE WITHIN ACCEPTABLE LIMITS OF ESTIMATED VALUES. IF NOT, TRY TO DETERMINE SOURCE OF ERROR

8. UPON RETURN TO USNO, TRIP REPORT MUST BE FILLED OUT WITHIN FIVE WORKDAYS AND DAILY LOG ON PC SHOULD BE TURNED OVER TO OPERATIONS GROUP AND DATA SHEETS SUBMITTED AS SOON AS POSSIBLE

**** EMERGENCY PROCEDURES FOR PORTABLE ATOMIC CLOCK ****

CLOCK TEAM MEMBERS: ____________________

____

LODGING: ____________________

PHONE ________________

IF ANY OF THE FOLLOWING SHOULD OCCUR PLEASE NOTIFY ONE OF THE CLOCK TEAM MEMBERS IMMEDIATELY.

1. KO-2 POWER SUPPLY
   A. AC POWER LIGHT GOES OUT
   B. IF POWER SUPPLY DC AMP METER IS READING GREATER THAN 0.6 AMPS.

2. 5061A CESIUM BEAM FREQUENCY STANDARD.
   A. IF BATTERY LIGHT (YELLOW) COMES ON.
   B. IF CONTINUOUS OPERATION LIGHT (GREEN) GOES OUT.
   C. IF ALARM LIGHT (YELLOW) COMES ON.

3. STATION POWER FAILURE.

   IF PRIMARY POWER REMAINS OFF FOR A PERIOD OF TWO HOURS AND YOU ARE UNABLE TO REACH ONE OF THE PORTABLE CLOCK TEAM MEMBERS,PLEASE DO THE FOLLOWING. IF ANY DC SOURCES 6V, 12V, 24 TO 30V RATED AT 120 WATTS ARE AVAILABLE AT YOUR LOCATION, CONNECT THE CLOCK TO THE SOURCE USING THE PROCEDURES LISTED BELOW. IF THESE DC SOURCES ARE UNAVAILABLE AT YOUR LOCATION YOU CAN RELOCATE TO ANOTHER BUILDING OR USE AN AUTOMOBILE BATTERY.

   A. LOCATE PORTABLE CLOCK TEAM'S TOOL BAG AND REMOVE THE DC POWER CORD.(IT WILL HAVE TWO BATTERY CLIPS ON ONE END)

   B. ON THE POWER SUPPLY, WHICH IS THE LOWER HALF OF THE PORTABLE CLOCK UNIT, TURN DOWN VARIAC TO ZERO AND REMOVE AC CORD FROM OUTLET.

   C. TURN SWITCH MARKED POWER (LOWER RIGHT FRONT PANEL,LEFT OF CONVERTER START BUTTON) TO EITHER 6V OR 12 V, DEPENDING ON VOLTAGE OF AVAILABLE SOURCE.

   D. FOR EITHER 6V OR 12V CONNECT DC POWER CORD TO POWER SUPPLY CONNECTOR WHICH IS MARKED DC IN. (REAR PANEL OF POWER SUPPLY LEFT HAND SIDE FROM REAR)

   E. CONNECT RED CLIP TO POSITIVE AND BLACK CLIP TO NEGATIVE TERMINALS OF SOURCE.

F. CHECK FOR AC LIGHT. IF ON, ADJUST VARIAC UNTIL DC AMP METER READS 0.4 AMP.

G. IF 6 VOLTS DC IS USED, IT MIGHT BE NECESSARY TO PRESS CONVERTER START BUTTON. (LOCATED ON RIGHT HAND SIDE FRON PANEL OF POWER SUPPLY.)

H. IF 24 TO 30V DC IS TO BE USED, YOU WILL NEED 2 BANANA PLUGS OR OTHER MEANS OF CONNECTING INTO POWER SUPPLY VIA DUAL CONNECTOR ON FRONT PANEL. IF 24 TO 30V DC IS USED, VARIAC IS OUT OF THE CIRCUIT AND AC ON LIGHT WILL NOT LIGHT AS THE VOLTAGE ONLY OPERATES THE CLOCK FROM DC AND DOES NOT CHARGE THE BATTERIES.

I. KEEP TRYING TO REACH THE PORTABLE CLOCK TEAM.

DAILY PORTABLE CLOCK AND POWER SUPPLY LOG

DATE ___/___/___

CESIUM S/N ________

DIAL SETTINGS
"C" FIELD ______ THUMBWHEEL ______
OSC FREQUENCY ______

CIRCUIT CHECK METER READINGS

BATTERY	___	MULT	___
SUPPLY	___	BEAM 1	___
ION PUMP	___	CONTROL	___
OSC OVEN	___	2ND HARM	___
CS OVEN	___	1 MHZ	___
5 MHZ	___	100KHZ	___

DAILY TIC TO PHASE ______

UNUSUAL PHYSICAL OCCURRENCES TO PC

VIBRATIONS/SHOCKS

TIME	LOCATION	CONDITION
___	___	___
___	___	___
___	___	___
___	___	___

TEMP CHANGES

___	___	___
___	___	___
___	___	___
___	___	___
___	___	___

ALARMS

___	___	___
___	___	___
___	___	___
___	___	___
___	___	___

POWER SUPPLY S/N ________

METER READINGS

	VOLTAGE	:	CURRENT
BATT 1	___	:	___
BATT 2	___	:	___
BATT 3	___	:	___
BATT 4	___	:	___
OUTPUT	___	:	___

TIME ON POWER SOURCE

	HRS	MINS	CHRG/DISC
AC POWER	___	___	
EXT DC	___	___	
PS BATTS	___	___	___
CS BATT	___	___	___

CHARGE	TIME UTC	RATE
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___
AC/DC	___-___	___

PC DEPARTURE AND READINGS ON RETURN AGAINST
SYS #1 ______ ______
SYS #2 ______ ______
SYS #4 ______ ______

REMARKS ____________________

QUESTIONS AND ANSWERS

MR. SAM WARD, JPL

Is that form that you used for the clocks which the team carries, is that available for use?

MR. PUTKOVICH:

Sure, everything -- all our data is available, anything we have is available.

MR. WARD:

I didn't mean the data, just the form.

MR. PUTKOVICH:

Sure, no problem.

MR. KLASKE:

It should be pointed out as portable clocks get better and better, actually you expect to see it looking like a time step, if you had a perfect clock, it would appear as a time step, simply because of the relativity.

MR. PUTKOVICH:

Nothing of the magnitude that I showed, it is very much smaller scale.

VOICE: Computer Science

How are clock visits initiated?

MR. PUTKOVICH:

Well, there are several ways, the best way to do it is to write a letter to the Superintendent, Naval Observatory, stating your needs, what your relation to DoD or the Navy is, and where you would like to have portable clock measurements made. And then you will get an answer back.

If you are on our usual route, you will get a portable clock measurement without too much trouble. If you are off our usual route, you are going to have to kick in a few bucks to pay for transportation and per diem and that sort of thing.

But it is available to components of DoD and DoD contractors. And if you are not off the beaten track, you can get a freebie.

MR. AL SWALGE, Frequency and Time Systems

You asked or indicated you were looking for improved clock power supply, could you elaborate a little on that?

MR. PUTKOVICH:

Yes, one of the problems is that the supplier that we are using now has been the workhorse and has been very good, I have not too much of a problem with that, but it requires -- it has idiosyncrasies like when you take it to Northwestern Australia where the power goes up to 270 volts in the evening, you tend to have smoke and bad things happen to your power supply.

QUESTION:

I don't know whose clock that might be.

MR. PUTKOVICH:

Well, that is a K02 power supply, it is a fantastic power supply, but it requires care and attention. It has sealed NiCd batteries in it, they have the memory problem, if you don't keep track of your discharge and charge cycles, you may end up on the short end of a power failure and that is bad for our clocks. Because once they stop, you are sort of out of luck and you might have $10,000 worth of effort down the tubes.

MR. ANDY CHI:

Do you care to tell us how the long-term, at-rest, data of the portable clock compares with the data when the portable clock is on the trip? Does it look continuous or are there many downs, as it goes through the trips.

Is the data continuous while the clock is in the laboratory and when you take it out to the trips, on a long-term basis, what do the data look like?

MR. PUTKOVICH:

Generally, I think, we could say that you see things as they were in the first two slides, either the frequency stays pretty much same, or you do occasionally get frequency changes. You rarely see the steps in time that occurred on the last two slides, unless something is wrong with the clock; and then you have a problem. You have taken a clock that is not performing well out on a trip and you get degradation of your data accordingly.

The high performance tubes that we are using in the portable clocks that we have now, perform quite well in that regard. The clocks that have the double loop integrators also show some improvement. So, they are performing fairly well.

DR. VICTOR REINHARDT, NASA/Goddard

Do you have a feel for the RMS frequency jumps that you see moving them around?

MR. PUTKOVICH:

No.