TIME DISSEMINATION - AN UPDATE

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Abstract

The original intent of this paper was to provide test results of the time transfers using a new Global Positioning System (GPS) Time Transfer Unit (TTU) developed for the U. S. Naval Observatory (USNO) by Stanford Telecommunications, Inc. (STI). As the TTU was not available for extensive testing at the USNO, only preliminary data were available at the time of the PTTI meeting. The scope of the paper was then changed to include several new developments in hardware and additions to services provided by the USNO in time dissemination in addition to reporting on results of time transfers utilizing the TTU and a new small portable atomic clock.

INTRODUCTION

The Precise Time and Time Interval Branch of the Time Service Division of the USNO is responsible for all of the hardware used in the monitoring and controlling of PTTI dissemination systems both local and worldwide. Included in this is the responsibility to publish and distribute the data gathered in a timely manner. In order to accomplish this within the constraints of limited available resources, the USNO relies heavily on the ingenuity and interest of specialists in the electronics industry to provide instruments that satisfy our stringent requirements. This paper provides a description of improvements that are being made to expand and enhance user services, a description of what is planned to improve the internal acquisition and reduction of data at USNO, a brief overview of new products that have become available due to USNO requirements and the initial results of tests conducted to determine the performance of two new time dissemination devices. These improvements provide the means to significantly improve time dissemination in a number of areas.

DATA AND SERVICES

In the past year or so several new or improved time data distribution services have been implemented. In the coming year plans call for several more significant additions.

The Telephone Time Service [(202) 254-4950 or Autovon 294-4950] was inaugerated just prior to the 1978 PTTI Meeting. Since then over 750,000 calls have been logged on the system. System availability has been approximately 99.7% over that period. Modifications were made to increase the message length from one fifteen second cycle to four, thus making the service available for a full minute per call. Ten telephone trunk lines are installed so overloads are infrequent and occur only at times of high interest, i.e. Daylight Saving to Standard Time, leap seconds, etc. The system provides direct access to the USNO Master Clock. Fail-safe operation is provided by requiring that the digital input signals from separate reference clock systems be coincident to within a few microseconds before allowing calls to be answered. Any discrepancy which would result in an incorrect announcement causes the system to go off-line until the problem is corrected. The message consists of a one pulse per second tick (5 cycles of 1000 Hz) and a voice announcement and tone to identify particular seconds of both Coordinated Universal Time (UTC) and local time in the Eastern U.S. Time Zone. To prevent distortion due to interference, the voice announcement is blanked for a short period, during which, the tick occurs. Three simultaneous, fifteen second announcements, spaced at five-second intervals, are continuously on line and provide a caller access to an announcement within five seconds of his call being answered. The precision obtainable by measuring the time of arrival of the tick is on the order of one millisecond. Measurements of this signal, made in Switzerland by Dr. Peter Kartaschoff, showed delays of 55 milliseconds via cable and 251 milliseconds via satellite. Users utilizing multi-hop satellite links would have to exercise care in making measurements as delays of a half second or more could be experienced.

Timing coverage on the Loran-C system has been extended with the synchronization of two new chains, U.S. Northeast Coast (9960) and U.S. Southeast Coast (7980). The creation of two new chains from the combination of the stations of the now defunct U.S. East Coast Chain (9930) with five new stations has resulted in an increase in both coverage area and signal strength and, in many areas, gives users a number of signals to chose from.

The reconfiguration of the East Coast Chain also resulted in the loss of the Cape Race, Newfoundland station as a dual-rated tie point for monitoring the North Atlantic chain performance. To alleviate this situation, the Observatory will install a monitor station at the Keflavik, Iceland SATCOM terminal to perform measurements on the North Atlantic and Norwegian Sea chains via the dual-rated station at Sandur, Iceland. Time transfers via SATCOM to Fort Detrick, Maryland and from there to the Observatory via TV Line 10 will provide the data necessary to accurately determine the timing performance of the two chains. Loran-C timing coverage will be further enhanced and expanded with the addition of the Great Lakes chain early in 1980 and the East Coast of Canada chain later that year.

The use of Earth satellites for time transfer and dissemination has always been of great interest to the Observatory. In addition to the routine operational use of SATCOM, Observatory personnel have been actively involved in nearly every satellite time transfer experiment performed (Telstar, Relay, Moon Bounce, ATS, Timation, Symphonie, etc.). Current efforts are centered around the Navy Navigation Satellite System, known as NNSS or Transit, and the Global Positioning System (GPS).

Although the Transit system has been in operation and available since the early 60's and the system's capabilities for precise time have been voiced by a number of proponents for a number of years, only recently, with the introduction of a commercially available Transit timing receiver, has the use of Transit time become realistic. The Observatory has published Transit timing information for a number of years in its Series 17, Transit Satellite Report. In recent years an effort has been made to improve the quality of the timing data available by seeking improvements in the satellite control procedures and by improving monitoring capabilities to allow the publication of data recovered from the satellite transmissions. The present generation of satellites (Oscars) provide a timing capability in the ±25 microsecond region with global coverage on a daily basis. We hope that improved control procedures could reduce this to less than ±10 microseconds for the Oscar satellites and to ±1 microsecond for the new generation of satellites (Nova), two of which are scheduled for launch in 1980. Unfortunately, efforts to improve control procedures have been unsuccessful to date. The Observatory will continue its efforts in this area and is currently engaged in upgrading its monitoring capability to allow the daily publication of more useful and timely information on all satellites in view from Washington.

The GPS, when fully operational, will have the timing capability of worldwide coverage on a continuous basis to a level of better than ±100 nanoseconds. Present proposals call for GPS time to be derived directly from the USNO Master Clock by means of a full GPS monitor station located at the Observatory in Washington. Monitoring by independent receivers will provide information for publication. The results of preliminary testing of the first receiver designed specifically for GPS timing will be presented later in the paper.

Another area in which the Observatory is currently engaged is the provision of access to Time Service data to users via a direct telecommunications link to our computers. This would provide real time availability of much of the data collected by the Observatory to any user who had a compatible modem and terminal.

COMPUTER HARDWARE AND SOFTWARE

The leading role that the Time Service Division has played in the development of automated systems for the collection and analysis of timekeeping information has continued and has become a major part of the Division's efforts. The now obsolete, but still operational, computer (IBM 1800) that is the mainstay of our automated system is being phased out and gradually replaced by two new minicomputers (IBM Series 1 and HP 1000). The integration of the new machines and the upgrading of the measurement system has turned out to be quite challenging. It is hoped that the two new machines, coupled to an IBM 4341 via a data communications link, will provide the improved performance, greater capacity and versatility and real time accessibility to data that is required. It is envisioned that the system will be able to accept data via a number of media (teletype, telephone, paper and magnetic tape, etc.) and will be able to output the processed information in printed form in several variations, electronically via telephone or teletype, in graphic form such as charts and view-graphs, on CRT terminals and so on.

The internal techniques and hardware for controlling the Master Clock system have been modified and refined to the point where the computer routinely adjusts the reference systems through a phase microstepper to a resolution of $\pm 1 \times 10^{-14}$. This is accomplished through a fail-safe interface designed and built at the Observatory. The programs for system control, the algorithms used in data analysis and the clock modeling techniques used in the prediction process were also developed at the Observatory.

Work is also proceeding in two related areas. The first is a multiplexer for controlling the multilayered, coaxial switch system used for data collection on the Observatory grounds. When implemented, this will allow several computers and terminals to access any clock or data source as necessary. Access will be prioritized and the systems configured to extend the redundancy presently built into the clock system to the data collection system. The second is the development and implementation of computer controlled remote measurement systems which can be accessed via dial-up telephone lines. A pilot system has been installed in the Fort Detrick, Maryland SATCOM terminal as a test-bed. The system is based on IEEE-488-1975 compatible equipment operated by an HP 1000 computer over an autodialed, switched commercial line at 1200 baud.

SYSTEM HARDWARE

In the area of system hardware, the Time Service Division operates under a philosophy of utilizing off-the-shelf, commercially available equipment to as great extent as possible. If a product does not exist to fill a particular requirement, an attempt is made to interest a manufacturer in designing what is required and adding it to his product line. In house developments are limited to items which can't be economically procured by any other means. In the past several years there have been a number of requirements generated by the Observatory that are now being satisfied by off-the-shelf products whose origins can be traced to the Observatory. The following is a brief description of the more significant of these, including mention of specific characteristics which make them unique.

The first five instruments (designed by Mr. Leonard Shepard of ILC/Data Devices Corp.) are a direct outgrowth of requirements which developed over the last few years as a result of a general increase in the use of PTTI, an increase in the capability and sophistication of the user community and the availability of higher quality clock systems. As the stability of frequency standards improved and clock modelling improved, the need for improving the control mechanism at the frequency standard output become apparent. As a result, a new phase microstepper was developed which increased the range of operation from $\pm 1 \times 10^{-8}$ to $\pm 1 \times 10^{-7}$ at the low end and from $\pm 1 \times 10^{-14}$ to $\pm 1 \times 10^{-17}$ at the high end, reduced the size of the phase steps from 10 nanoseconds to 1 picosecond and reduced instabilities to less than 500 picoseconds for a laboratory environment. This instrument is currently undergoing testing and should be in production early in 1980.

With the advent of measurement systems with subnanosecond resolution, the need to develop more well-defined and stable one pulse per second signals from the highly stable frequency standards came into existence. This need was satisfied with the clock/divider shown in Figure 1. It provides four independently buffered 50-ohm outputs (with port to port delay variations of less than 1 nanosecond) having rise times of less than 4 nanoseconds, jitters of less than 50 picoseconds and stabilities of better than 20 picoseconds per degree Celsius. In addition, a BCD output, a high visibility LED display and an audible tick are also provided.

As an adjunct to the above units, a pulse distribution amplifier (Figure 2), utilizing the same output circuits as the clock/divider, is available in configurations of up to 20 channels per unit. This allows the distribution of highly stable, isolated pulses over a large area without fear of system degradation due to line loading or other inadvertent interference.

Until recently, commercially available TV Line 10 time dissemination equipment suffered from a common fault. Television receivers designed for home use were used to recover the transmitted signal. The chief problems were due to the low quality of the components (compared to laboratory grade equipment) and the resultant instability and reliability. The TV Line 10 system offers an inherent capability for local time dissemination in the tens of nanoseconds under certain circumstances. In order to achieve this capability an instrument grade receiver (Figure 3) was designed and built. Utilizing these receivers, results well below 50 nanoseconds have been achieved. Efforts are currently under way to stabilize local TV transmissions using modified versions of the receivers to generate the required sync signals at the transmitter and thus achieve a stability below the 10 nanosecond level.

Time dissemination requires the ability to make high resolotion, precise time interval measurements. Time interval counters used on portable clock trips have additional constraints in size and weight requirements. The most desirable situation is that of high resolution in a small package. After several unsuccessful procurement attempts, a counter designed specifically for portable clock applications has been built (Figure 4). The counter is contained in a package 1.75 inches high and 9 inches wide and weighs four pounds. It has a built-in digital voltmeter for setting the trigger levels, has a single shot resolution of 10 nanoseconds and an averaging resolution of 1 nanosecond.

TIME DISSEMINATION HARDWARE

The final two items, which have become available only in the last few months after several years of development, are a small portable atomic clock and a GPS Time Tranfer Unit. Both are the result of requirements and support generated at the Observatory. As a large part of the Time Service Division's mission is concerned with the dissemination of PTTI, more efficient and accurate means of time transfer are of vital interest and a continuous effort is made to improve operations in these areas. Over the past twelve years the Observatory has conducted portable clock operations that have resulted in the synchronization of of between 100 and 200 clocks yearly on a worldwide basis. The cost per clock synchronized can be anywhere between $500 and $1000 and three to four man-days of effort. Because of their size and weight, portable clocks presently in use pose logisitical problems and require special handling to prevent injury to personnel handling them. Ways to reduce the physical and financial burden of these trips are constantly being sought.

The small portable cesium clock shown in Figure 5 is a product of Frequency and Time Systems, Inc., and it should have a significant impact on portable clock operations. Being slightly larger than a normal briefcase and weighing less than fifty pounds, it can be handled by one person and carried under most commercial aircraft seats. This makes possible an immediate cost reduction due to the elimination of the need for a seat for the clock and will allow the elimination of a second clock carrier on certain trips. As the clock has seven to eight hours of internal battery capability and provisions for operation from 115/230 VAC, 50 to 400 Hz, and 12 VDC it can operate in the same power environment as the larger clocks. The performance of the clock was recently evaluated on a seven-day trip to California. Two portable clocks were transported by auto and aircraft to a number of locations in and between Los Angeles and San Francisco. One was the small portable (designated FTS PC 101) and the other was a large portable (designated HP PC 1452). HP PC 1452 consisted of a Hewlett-Packard high performance cesium clock and standby power supply, a combination that has given outstanding service for many years. At each site visited, measurements were made using both clocks. The results of these measurements are shown in Figure 6. The end points of the lines are measurements made at the Observatory at the beginning and end of the trip. The lines are interpolated estimates of clock performance during the trip. The data points plotted are the measurements made during the trip. If HP PC 1452 is assumed to be perfect and all the error assigned to FTS PC 101, we would assign the maximum deviation of approximately 50 nanoseconds to FTS PC 101. Since this is certainly not the case and since a curve fitted through the data points would be within 25 nanoseconds of the interpolation, the performance of the FTS PC 101 can be described as outstanding, well within the error one normally experiences on extended trips. The positive bias of the data indicates non-linear performance on the part of one or both clocks or some measurement error in the endpoint measurements. Efforts will be made to evaluate performance more fully in months to come.

The reason for this portable clock trip was to test a GPS/TTU at Stanford Telecommunications, Inc., Sunnyvale, California. The TTU was developed and built for the Observatory with funding from the Naval Electronic Systems Command. The GPS/TTU is intended to be a test-bed from which the timing performance of the present GPS phase can be evaluated, a monitor receiver from which operational GPS time dissemination can be carried out on an experimental basis, and a system prototype which will provide the information necessary to develop the next generation of GPS timing receivers.

The GPS/TTU is illustrated in the block diagram of Figure 7 and the photographs of Figures 8 and 9. The system consists of an antenna, preamplifier, receiver, processor, time interval counter, CRT terminal and power supply. After the equipment is powered up, the operating system and application programs are loaded in from magnetic tape cassettes and the time of day set. Execution of the application program begins with selection of various options for system operation and data collection, processing and recording. Data base parameters, such the geodetic location of the receiver, receiver delay and UTC-GPS time offset are entered from a tape or via the keyboard. The satellite acquisition procedure is then initiated by setting in the satellite identification number and an estimate of the expected doppler. Once initialized the system automatically acquires and tracks the selected satellite and records the data.

The receiver utilizes the C/A code on the L1 carrier frequency. The data from the C/A code is used to determine the satellite position and to estimate the time of arrival of the satellite subframe epoch. The estimate is corrected for ionospheric, tropospheric and relativistic errors and compared with the actual time of arrival as recorded by the counter. The difference between the actual time and the estimate is the difference between the local clock and the satellite clock. This process is repeated and data recorded for every six-second message received while the satellite is in view and the receiver is tracking.

The evaluation of TTU performance consisted of establishing the difference between GPS and UTC utilizing a high performance portable clock and then using the same clock as the input to the TTU and measuring the same quantity utilizing the satellites. The evaluation was performed during the period from November 14 to 19, 1979. Portable clock HP PC 1452 and FTS PC 101 were transported to the GPS Master Control Station (MCS) at Vandenberg AFB, to the contractor's plant in Sunnyvale, back to the MCS and then back to Sunnyvale. At each location measurements were made. The results of these measurements are shown in Figure 10. The data are presented with all clock biases and offsets removed and represent the actual measured differences between the GPS clock at the MCS and that same clock measured via the satellites. The two data points designated with an X are GPS time as defined by the atomic clock at the Vandenberg MCS receiver site. The circles and triangles are satellite values measured using the TTU in Sunnyvale. All data received via the satellite fall well within the ±100 nanosecond limits established in the system specification.

CONCLUSION

This paper has provided a brief description of some of the improvements that are being made in the generation and dissemination of PTTI at the U. S. Naval Observatory. Details on some of the newer hardware developed for this purpose were presented. Data from tests of two of the more significant items, a small portable clock with performance approaching that of larger units and a GPS Time Transfer Unit capable of time transfers to an accuracy of less than 100 nanoseconds, were also given.

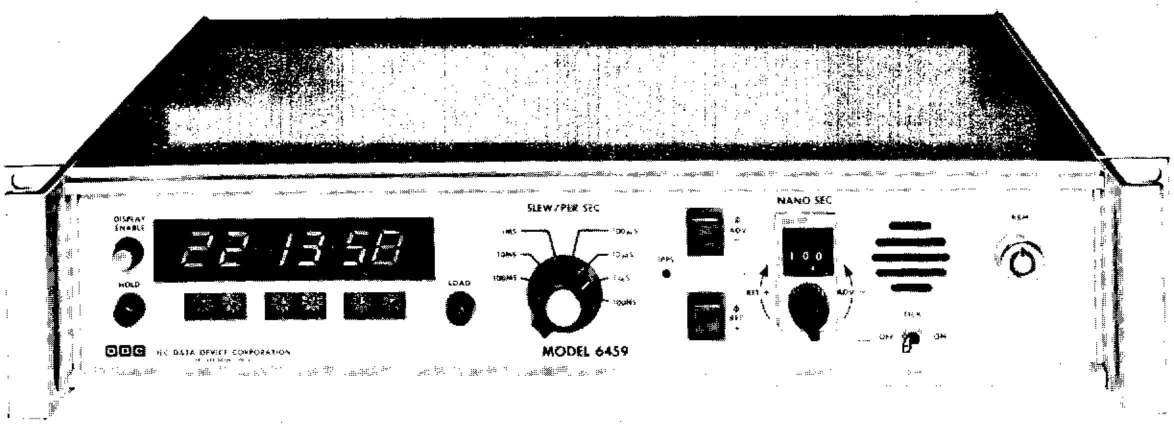

Figure 1. High Stability Clock/Divider

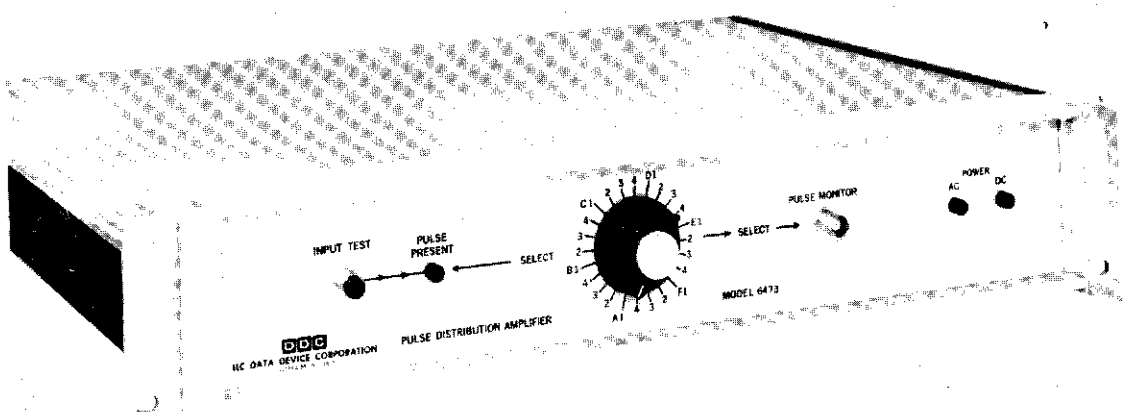

Figure 2. Pulse Distribution Amplifier

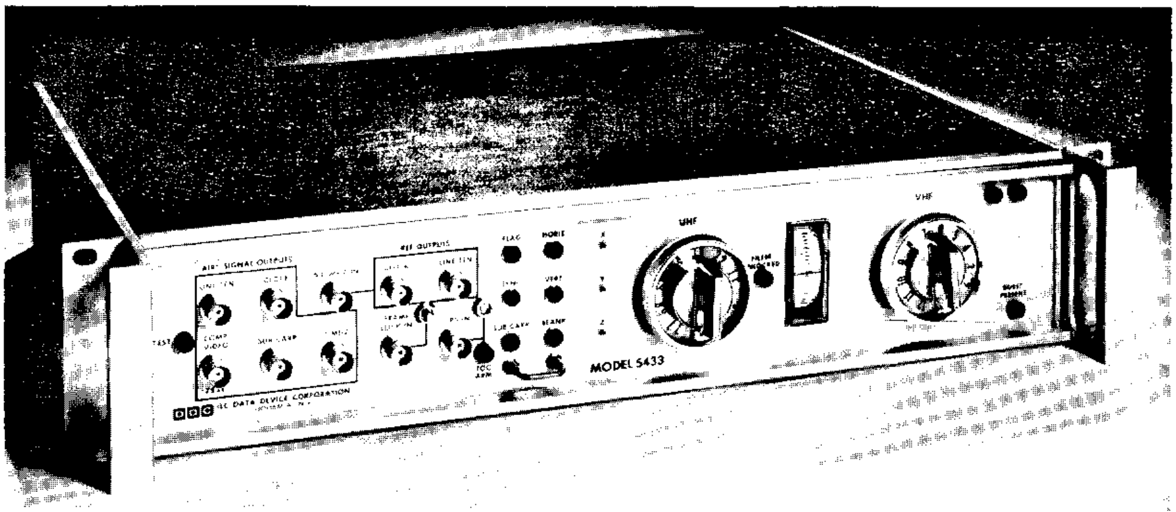

Figure 3. Precision TV Line 10 Receiver

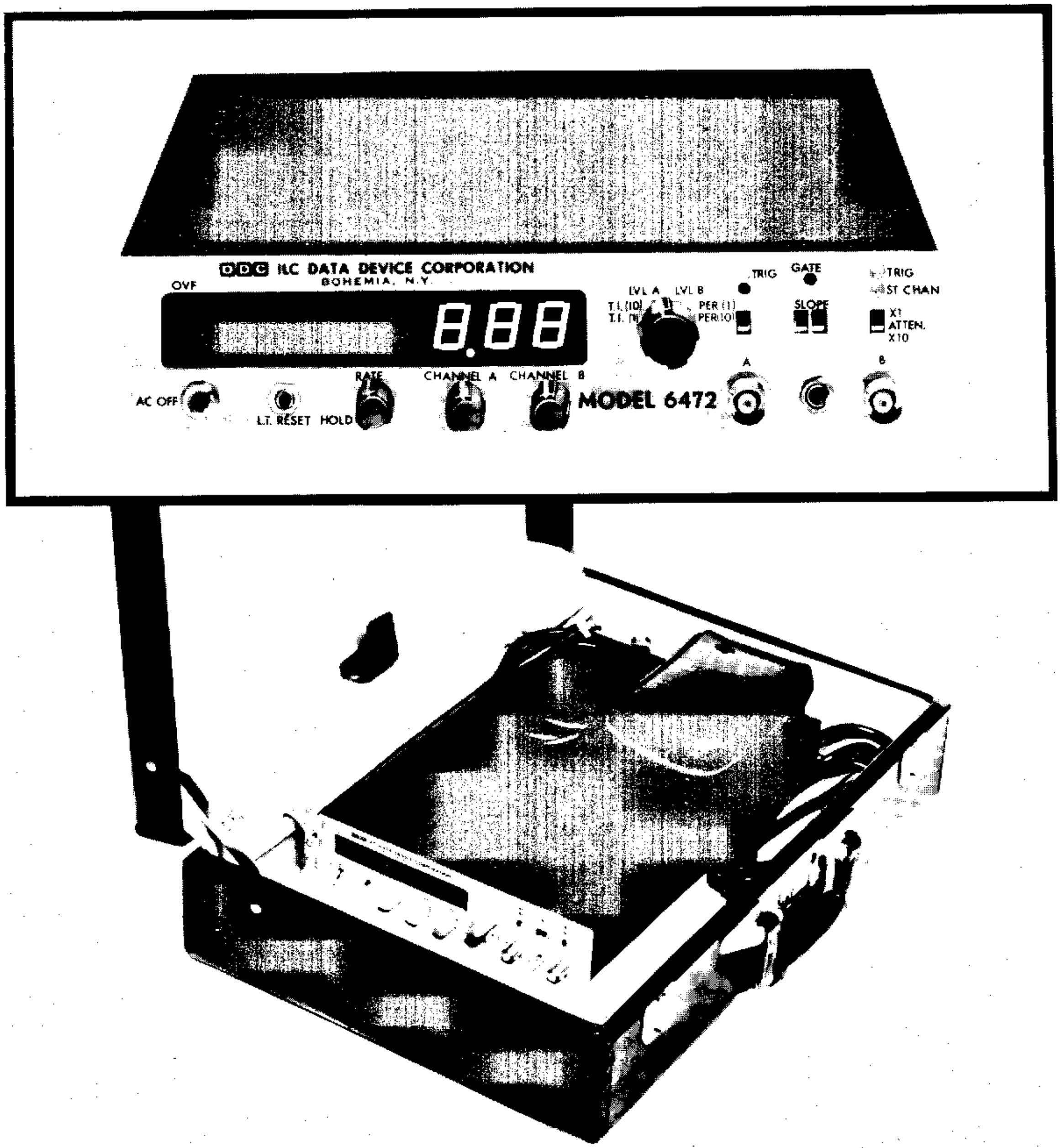

Figure 4. Small Time Interval Counter

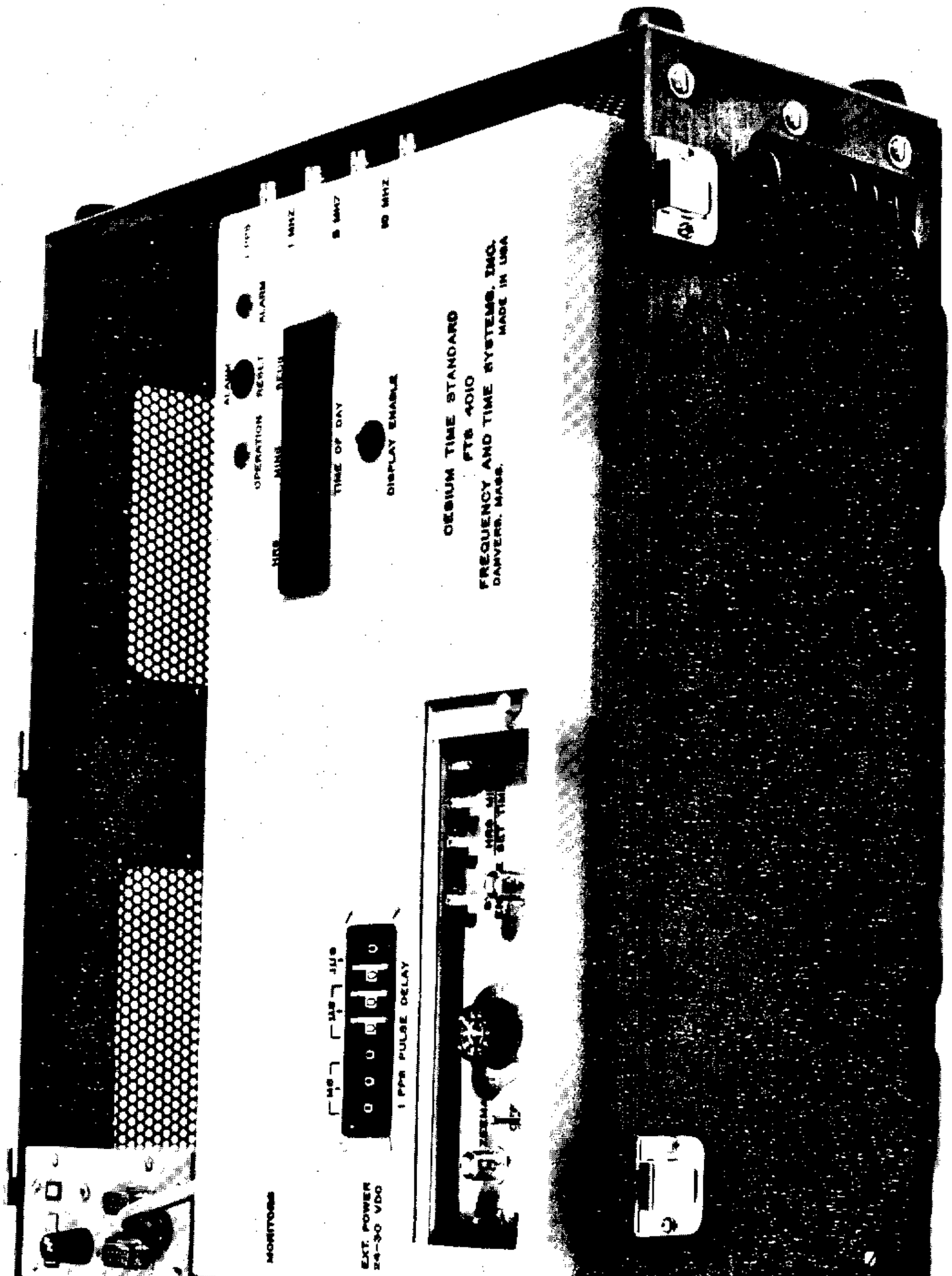

Figure 5. Portable Atomic Clock

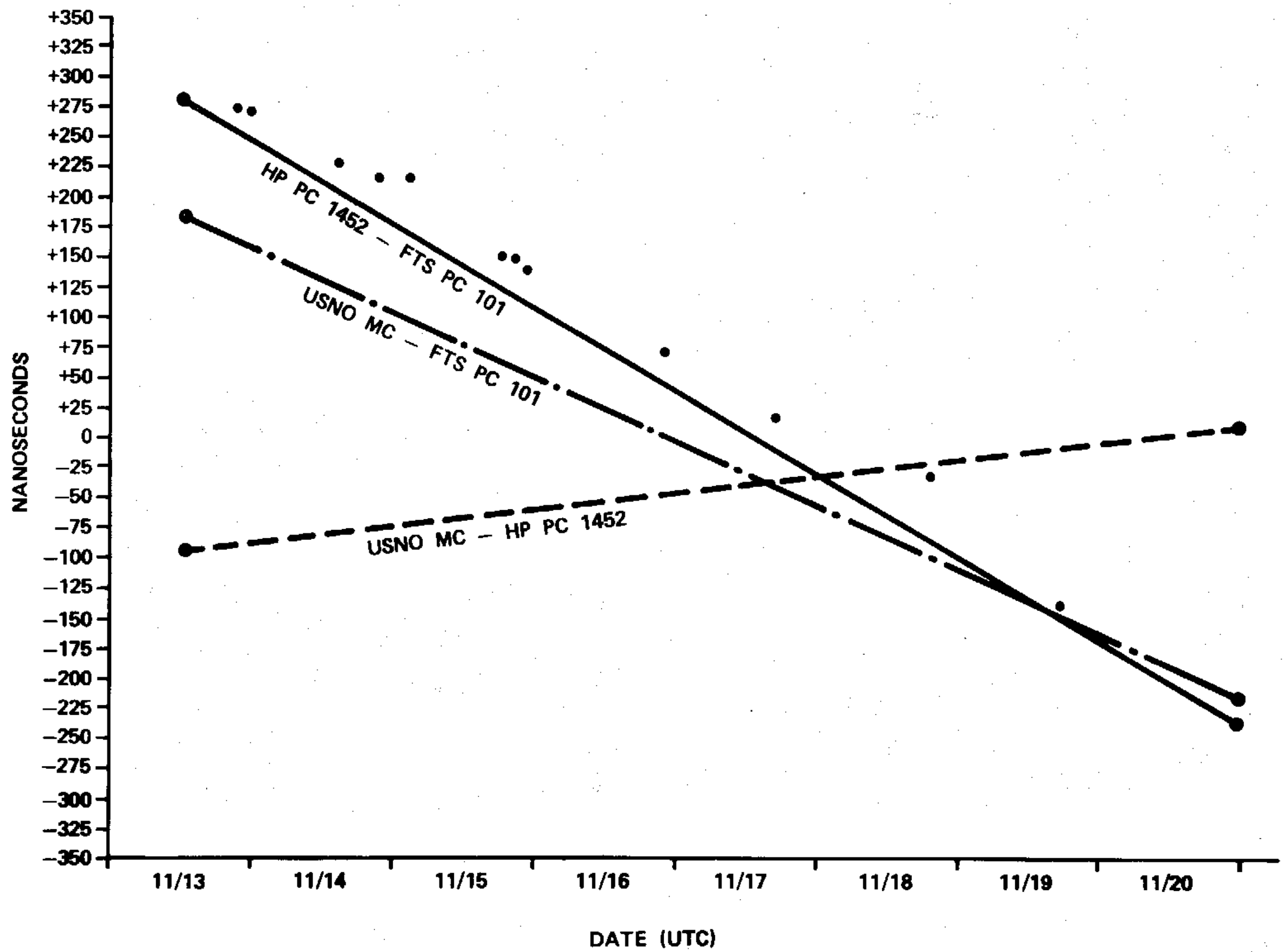

Figure 6. Small Portable Clock Performance

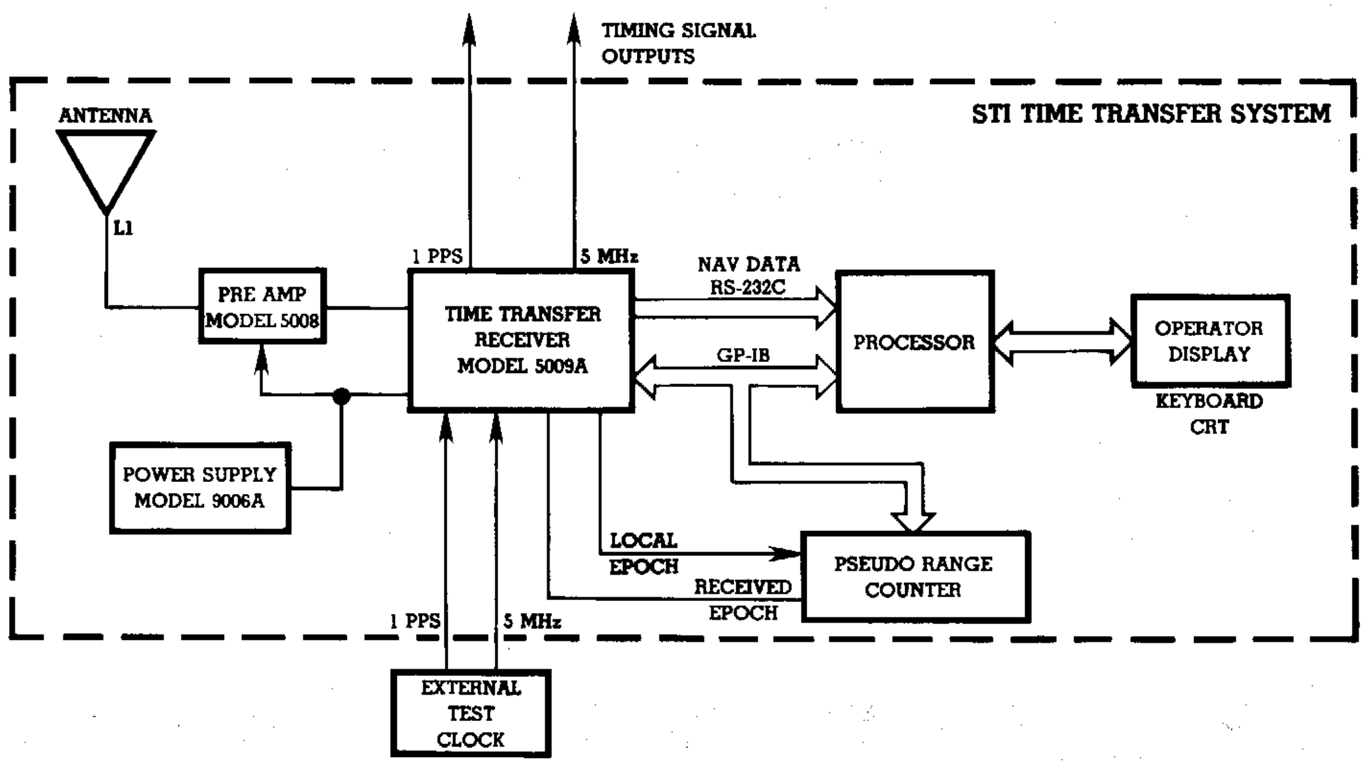

Figure 7. GPS/TTU Block Diagram

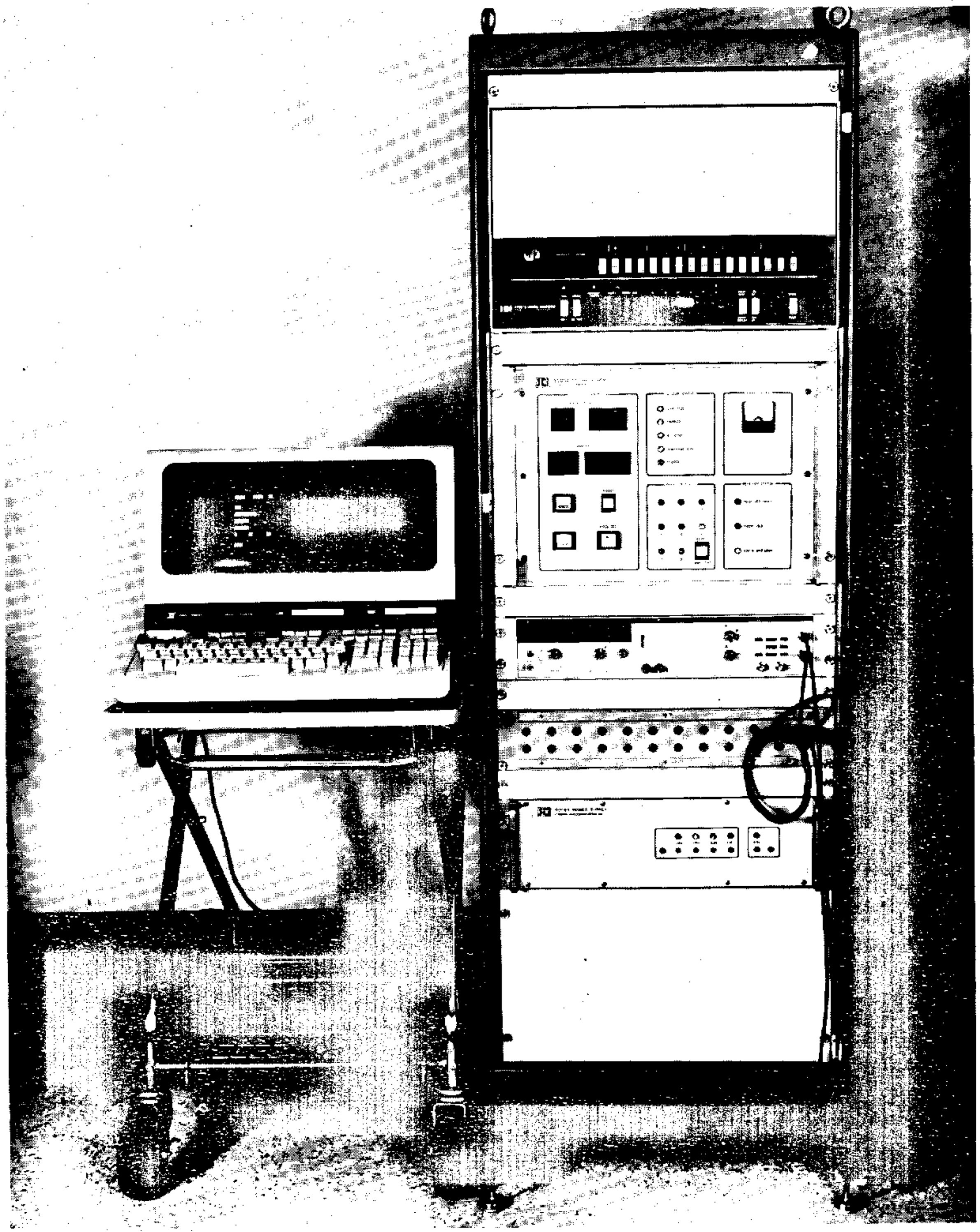

Figure 8. GPS/TTU System (Less Antenna)

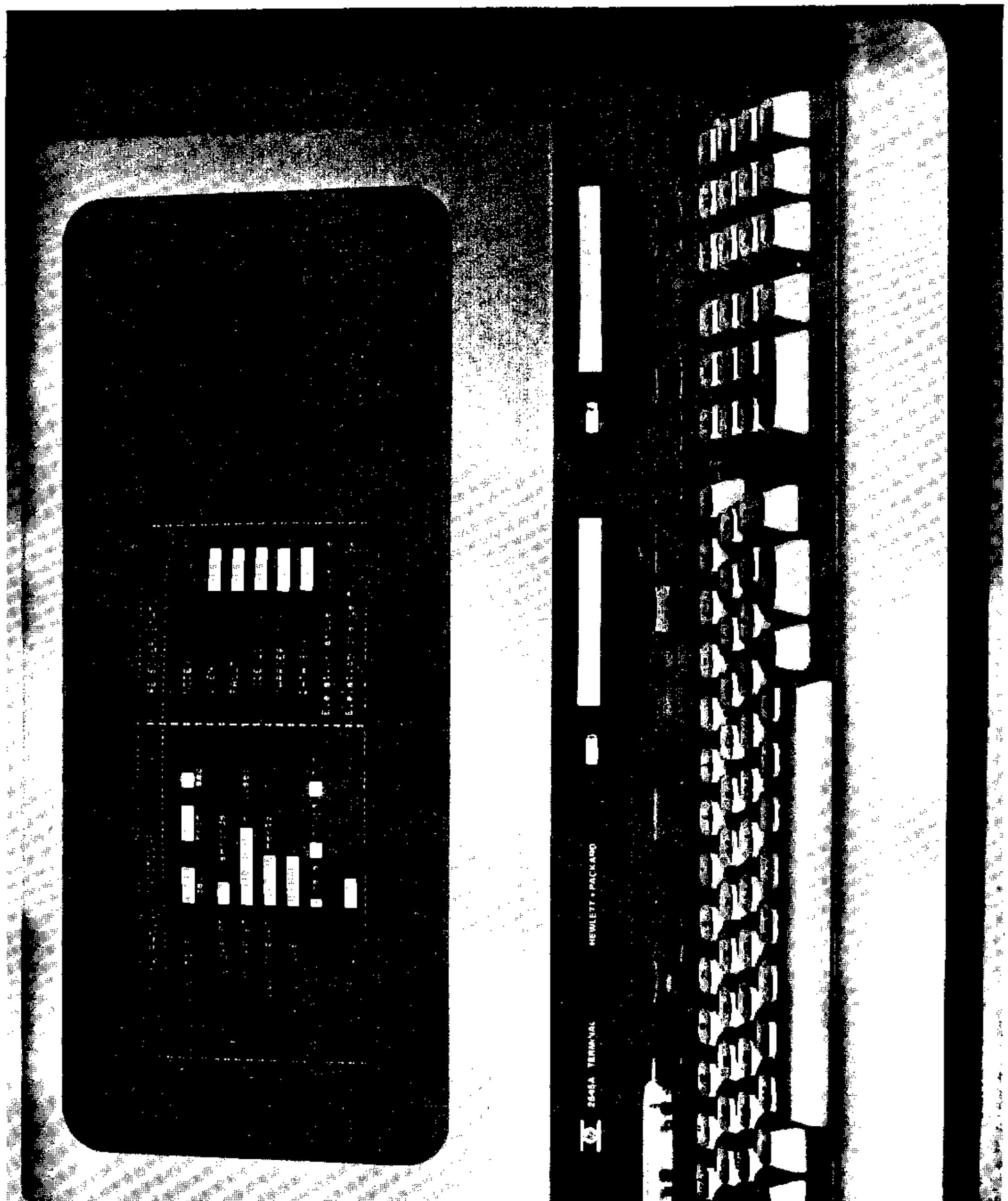

Figure 9. GPS/TTU Console and Display

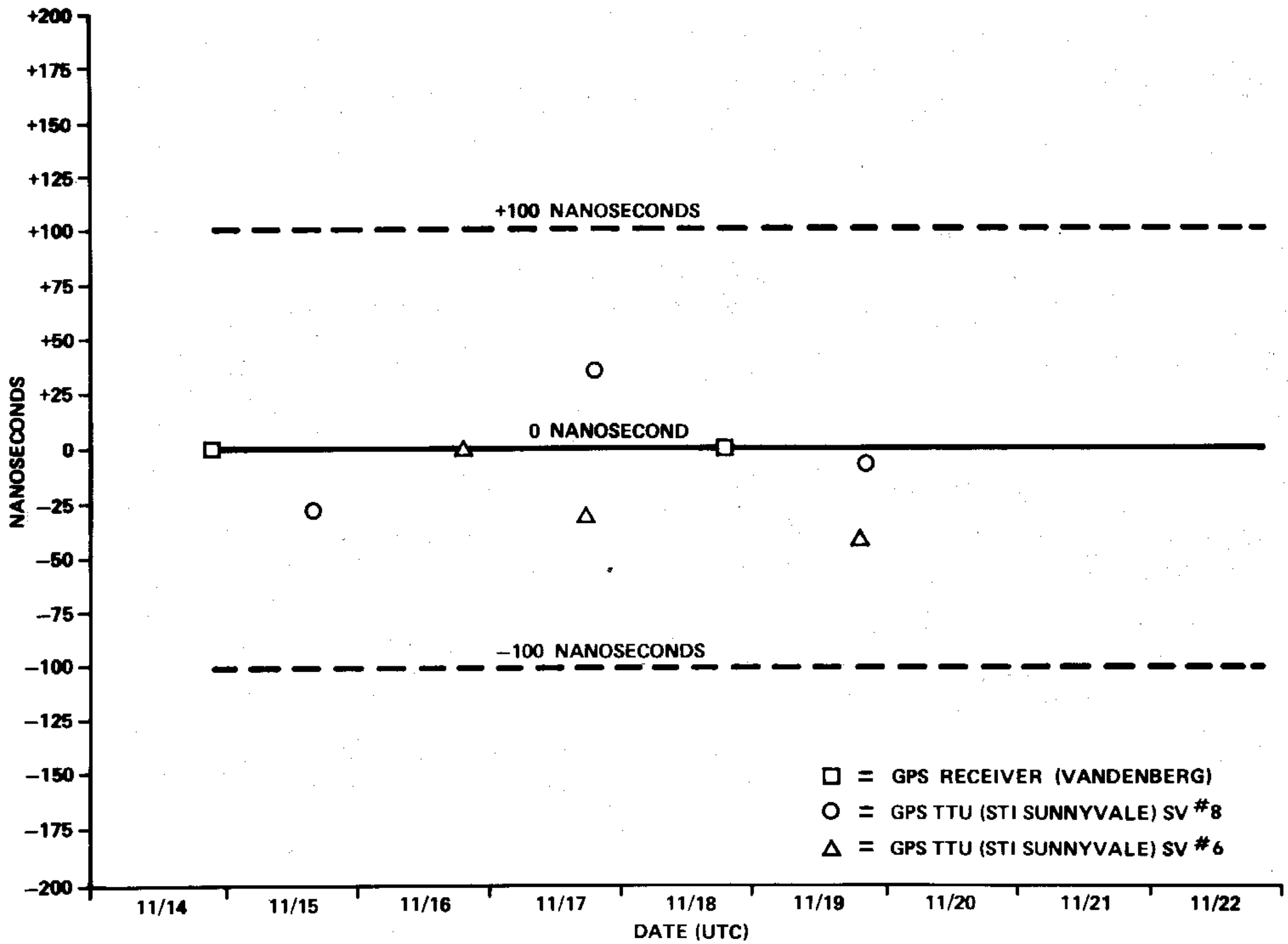

Figure 10. GPS/TTU Preliminary Test Results

QUESTIONS AND ANSWERS

MR. MYRON PLEASURE, Consultant Physicist, New York

In December of last year there was a paper published in "Physical Review Letters". It was a feature paper by a Professor Cohen of the University of Pennsylvania in which he suggested using your time dissemination methods from satellites and coordinating it with ground measurements which he said were easy, though they are not, and then you could use that to check the Einstein special relativity theory of what errors you would expect due to the satellite motion. Now, have you done any estimates of this yet? How well is it-- He has an approximate theory only. It was in the "Physical Review Letters".

DR. PUTKOVICH:

Could I defer the answer to Dr. Winkler here?

DR. WINKLER:

The corrections due to the general relativity are incorporated in the calculations or the algorithms which are used in the STI receiver. With all of that, you should have no visible effects if you put in your coordinates of the station, the receiver algorithm will take into account the relativity effects. There are some higher order effects which are incorporated in the second order corrections for the satellite clock so that the motion of the satellite itself is accounted for.

But in general the whole subject of relativity as it effects the GPS system has been reviewed repeatedly, the last time in a conference or a workshop organized by Dave Allan at the NBS which produced a report of that. And in the judgment of that group, also there were minor discrepancies found in various reports, but the effects seemed to be taken account in the existing algorithms. Thank you.

MR. RAULLO J. MCCONAHY, APL/JHU

We have a program at our laboratory that can use your timing recovery from GPS and I was wondering if you could give us a little more information about when you plan to disseminate those and how.

DR. PUTKOVICH:

We will be taking delivery of our GPS time transfer unit in, I would say, two to three weeks and we will have an initial testing period, but I would hope that sometime in January we would be able to start publishing differences between the USNO master clock and the received signal from the spacecraft that are now up there, the four GPS satellites.

MR. MCCONAHY:

Then you will be doing all four? The clocks on some of them are not too good, like GPS-2, for example.

DR. PUTKOVICH:

That is why we only took these two. We took the two best satellites that were recommended and operated on those two. But we will take a look at it and if the data is reasonable, I don't see any reason why we can't publish it. It is just a matter of scheduling people to take the passes at the proper time. If it gets to be too big of a burden we may have to make some choices as to what we publish. But initially I would hope that we could look at all four of them.

MR. MCCONAHY:

Could it be possible to request you to do passes on a given day for example?

DR. PUTKOVICH:

I don't see why not. If it is at 2:00 or 3:00 in the morning you will have problems getting me in there to do it, but I may be able to find somebody that is willing.

MR. MCCONAHY:

Yes. Our need is just periodic and we need it on a specific day.

DR. PUTKOVICH:

We have done that with TRANSIT with some people and there should be no reason why we can't do it with GPS.

MR. MCCONAHY:

Now another question is why did you choose the CA code rather than the P code to do your timing?

DR. PUTKOVICH:

I had nothing to do with that choice. I think that is a code that more than likely will be available other than the P code. I think Dr. Winkler can also give you more insight in that.

DR. WINKLER:

Cost. Because of the type of receiver we were looking at, and the possibility of using the existing equipment for a stationary location in contrast to an option on a type of navigation equipment which would have to look at four satellites and possibly use two frequencies for this purpose would be inherently more expensive.

MR. MCCONAHY:

Yes. But you could correct for the ionosphere.

DR. WINKLER:

We want a simple clock and that means that by confining yourself to just one frequency in CA code, a one megahertz code, it would be easier and less costly to decode. It is possible to obtain a time transfer which will satisfy all current operational criteria.

MR. MCCONAHY:

Thank you.