PERFORMANCE OF LORAN-C CHAINS RELATIVE TO UTC

A. R. Chi
Goddard Space Flight Center

ABSTRACT

With the advent of space science and applications the requirements for precise and accurate time and time interval have approached to the order of microseconds and below. To meet these needs users must examine the various techniques to maintain the time scale and assess their long-term performance.

Loran-C navigation system has been widely used in the last few years as a precise time reference signal for international comparison of the primary clocks in the northern hemisphere. This paper presents the long-term performance of the eight Loran-C chains in terms of the Coordinated Universal Time (UTC) of the U.S. Naval Observatory (USNO) and the use of the Loran-C navigation system to maintain the user's clock to a UTC scale.

The atomic time (AT) scale and the UTC of several national laboratories and observatories relative to the international atomic time (TAI) are presented. In addition, typical performance of several NASA tracking station clocks, relative to the USNO master clock, is also presented.

Recent revision of the Coordinated Universal Time (UTC) by the International Radio Consultative Committee (CCIR) in its 13th Plenary Assembly is given in an appendix.

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INTRODUCTION

National time keeping and maintenance agencies for each country have primary responsibilities in the maintenance and dissemination of accurate time to the users. These primary clocks which provide the accurate time are maintained on a long term basis and are traceable to the origin of an epoch. The time signals[1] are disseminated through radio frequency emissions or other techniques to users, including other national time keeping agencies. The international comparisons of time signals among the national time keeping agencies comprise the data base for the adoption of uniform time scales such as the Coordinated Universal Time (UTC) and the International Atomic Time (TAI). It is the time as a scale rather than the time as an epoch that is in increasing demand by modern users.

With the advent of space science and applications in the last decade the requirements for precise and accurate time and time interval have approached the capabilities of national time keeping and maintenance agencies. To satisfy the sophisticated users, the national time keeping agencies issue time corrections periodically in the form of bulletins or announcements. These corrections are given relative to a primary time standard or master clock. For example, the Bureau International de l'Huere (BIH) issues a monthly circular, circular D, which gives the time comparison between the various national time standards relative to UTC and TAI. The use of these bulletins, announcements, and circulars and the long term stability of the primary time standards relative to the internationally adopted time scales is presented in this report. Users who need precise and accurate time and time interval on the order of microseconds or better undoubtedly recognize the need to use these corrections. The proper interpretation of the user's requirements in terms of time or time interval, the difference between accuracy and precision of measurement, and the accuracy of maintaining a clock relative to a time scale is generally the responsibility of the users who must communicate effectively to those experts who generate and maintain the time standards and/or who provide the techniques for clock synchronization.

CLOCK COMPARISON TECHNIQUE AND DATA

Clock comparison techniques are numerous and vary in accuracy and precision. In general, radio frequency transmissions in VLF, LF, and HF bands have been used as the work-horse and provided continuous, reliable and real-time time transfer references for clock comparisons. Portable clocks, satellites (both natural and artificial), and coherent radiations from quasars are in increasing use to meet specific needs. As the accuracy in timing requirements is increased, not only must the accuracy of transmission and the precision of measurement be increased, but also the stability of the oscillators (fly wheel) which generate the time must be increased.

The most often used time transfer reference signal for clock comparison among primary clocks in national laboratories is the 100 kHz transmissions of the Loran-C navigation system. At present, Loran-C consists of eight chains which provide coverage for the northern hemisphere. The resolution of time comparison of an identified cycle of the received signal is about 1/100th of a cycle or 0.1 microseconds. The long term stability of the propagation delay, even for groundwave, is probably not much better than ±0.5 microsecond. The long term stability of the time transmission of a Loran-C chain at present is about one order of magnitude lower. The requirement imposed by users to the U.S. Coast Guard who operates the Loran-C chains for controlling the emitted time relative to the master clock of the U.S. Naval Observatory is much larger. This requirement has been stated between 15 and 25 microseconds. The performance of the Loran-C chains varies from chain to chain but is better than the stated requirement.

The data collected by each national laboratory or observatory is published and is available to the users. For example, in the United States the Naval Observatory issues to general users a series of time bulletins and announcements on a weekly basis, and sends corrections by telegrams on a daily basis to special users. The National Bureau of Standards issues a special publication, NBS Special Publication 236, on a monthly basis. In other countries, for example in the United Kingdom. the Royal Greenwich Observatory publishes a monthly Time Service Circular. Also, the National Research Council of Canada publishes their Loran-C measurements in letter form once every ten days and Time and Frequency Bulletins monthly. The Institute Electrotecnico Nazionale of Italy publishes a monthly circular and the Bureau International de l'Heure publishes monthly circulars and annual reports. The contents, as well as the frequency of publications vary as do the needs. In general, the information is readily available and the publications can be had upon request. Typical time service notices, bulletins, announcements, and circulars are given in Appendix A.

HISTORICAL BACKGROUND OF ATOMIC TIME

Present primary time standards, as maintained by national laboratories, are based on cesium atomic oscillators which are made either in the laboratories or by a commercial firm. The time maintained by these oscillators is referred to as atomic time. Historically, A.1 was the weighted average of nine cesium atomic standards which were located in nine laboratories in four countries.[2] This average was maintained by the U.S. Naval Observatory (USNO). A.1 is presently the average of an ensemble of 15 to 30 commercial cesium atomic standards maintained at the USNO.[3] Each individual national laboratory also maintained an atomic time scale identified with a laboratory such as the U.S. Atomic Time (USAT) of the National Bureau of Standards which is now known as AT (NBS). Other examples are the Greenwich atomic time (GA) and now the GA2 of the Royal Greenwich Observatory, and the A3 of the BIH.

As the various atomic time scales went through the process of evolution it became obvious to many that an international standard must be adopted.[4,5] Thus, the XIIIth General Conference of Weights and Measures (CGPM) adopted in 1967, the definition of the second as "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom 133." The CGPM also defined International Atomic Time (TAI) as "the time coordinate established by the BIH on the basis of the readings of atomic clocks operating in various establishments conforming to the definition of the second, the unit of time of the International System (SI) of Units."

The XIIth Plenary Assembly of the International Radio Consultative Committee (CCIR) of the International Telecommunication Union, adopted in 1970 the improved UTC system. The improved UTC system was revised by the XIIIth Plenary Assembly of the CCIR in 1974 as given in Appendix C. This system eliminated the changing frequency offset between UTC and TAI and increased the step-time adjustments from 0.1 to 1 second which is now called a leap second.[6] Thus the UTC and TAI have the same rate.

CLOCK COMPARISONS

Based on the published clock correction data of BIH, the atomic time scales, as maintained by several national laboratories and observatories, are plotted for 900 days as shown in Figures 1 and 2. In these figures the ordinate is plotted as the clock difference, Δt, in microseconds between TAI and the AT of a laboratory shown in parenthesis. The three abscissas shown are the elapsed time in days, the Modified Julian Day (MJD), and the year, month, and day (YR, MO, DY). The clock off-sets of the several laboratories were not removed, for historical reasons or by choice, so as to maintain a continuous time scale for the particular laboratory.

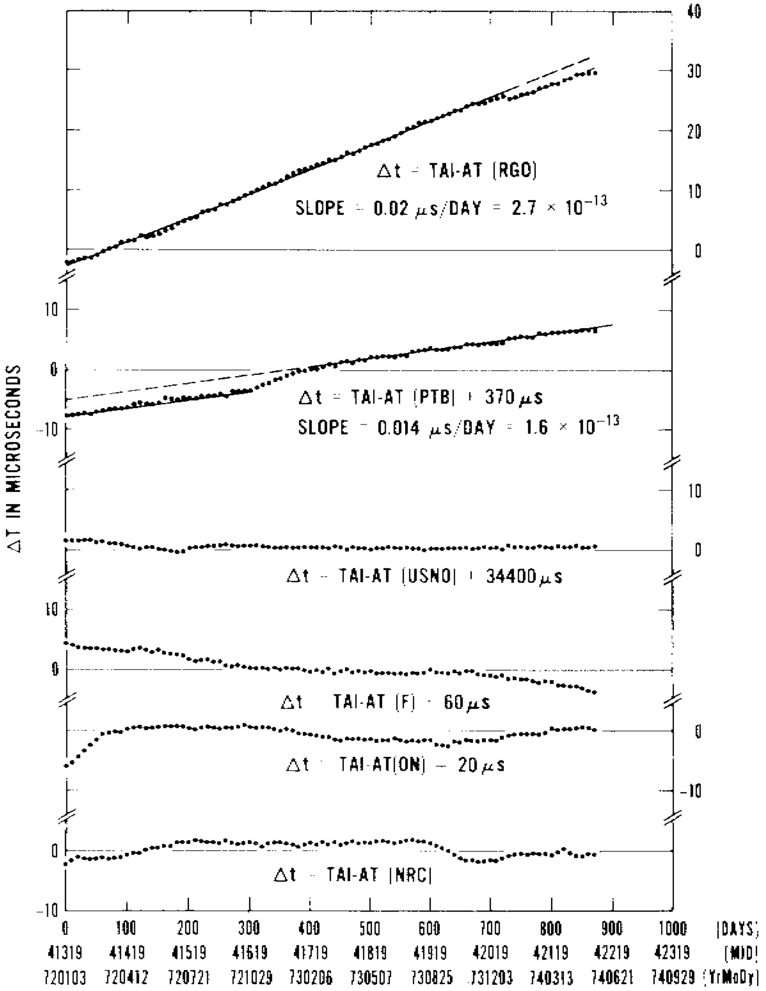

Fig. 1—Independent Local Atomic Time Scales, AT (Laboratory-i), Relative to TAI (International Atomic Time). (Data Source -- Circular D Bureau International de l'Heure)

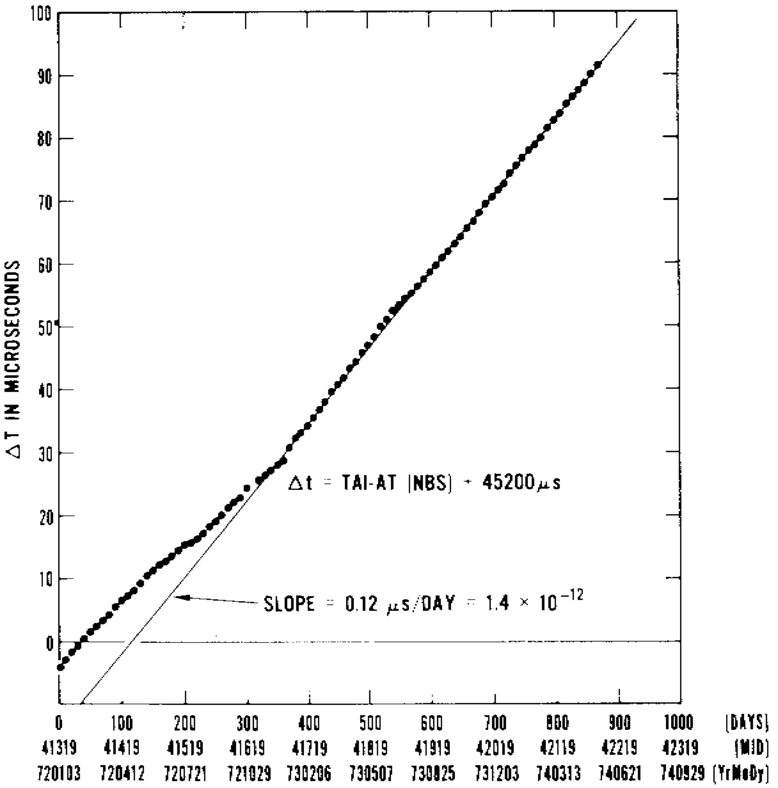

Fig. 2—Independent Local Atomic Time Scale, AT (NBS), Relative to TAI (Continued From Figure 1)

In Figures 1 and 2 these clock offsets were arbitrarily chosen so that the origins of the curves are near zero. The larger slope or clock rate difference between TAI and AT (NBS) shown in Figure 2 is attributed to the frequency difference between laboratory and commercially made cesium atomic standards.[7] Although the Physikalisch-Techische Bundesanstalt (PTB) of Federal Republic of Germany and the National Research Council (NRC) of Canada also have laboratory made cesium atomic standards, it is not known if these standards are used to steer their working standards, which are commercially made cesium atomic standards. Atomic time scales are maintained by national laboratories; their relation to the International Atomic Time Scale is of interest. Only through this known relation can the time variant data collected by experimenters in different countries be correlated and compared.

Those measurements which are dependent on the earth's position are made relative to the Coordinated Universal Time (UTC). The UTC of each laboratory relative to the UTC of BIH is also plotted for 900 days as shown in Figures 3 and 4. The difference between UTC (BIH) and TAI is -10 seconds as of January

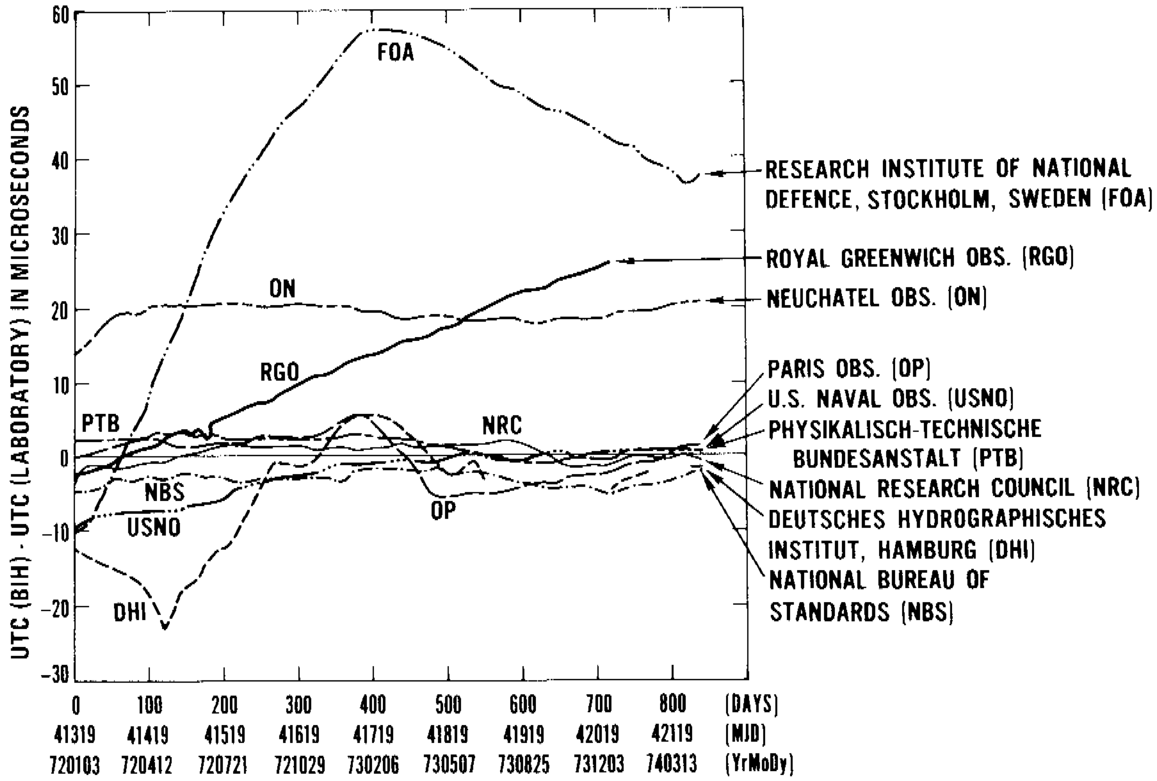

Fig. 3—Coordinated Universal Time (UTC) Scales of Independent Laboratories Relative to UTC (BIH) (Data Source -- Circular D, Bureau International de l'Heure)

1, 1972 (with the negative sign indicating UTC late), -11 seconds on July 1, 1972, -12 seconds on January 1, 1973, -13 seconds on January 1, 1974, and -14 seconds on January 1, 1975.

Figure 5 shows the UTC time comparison of three national laboratories for 550 days using the East Coast chain of the Loran-C navigation system as the time transfer reference signal. The East Coast chain consists of five stations with the master station being located at Cape Fear, North Carolina and four slave stations located at: Jupiter Inlet, Florida; Cape Race, Newfoundland; Nantucket, Massachusetts; and Dana, Indiana. Also shown at the bottom of the figure is the time difference between UTC (USNO) and UTC as transmitted by the Mediterranean Sea chain. Thus, these data permit the time comparison between the East Coast and the Mediterranean Sea chains using UTC (USNO) as the time transfer reference. The obvious single break in the East Coast chain data, which occurred on MJD 41994 (Nov. 8, 1973) are due to step time corrections made at the master stations as are the two breaks in the Mediterranean Sea data which occurred on MJD 41840 (June 7, 1973) and on MJD 42090 (Feb. 12, 1974). The smaller step time corrections and frequency changes of the oscillators made from time to time at the master station will become obvious when the detailed data is examined. It should be pointed out here that the time transmitted by Loran-C chains is required to be within only ±25 microseconds of the master clock of the U.S. Naval Observatory (USNO MC). This requirement (as can be seen in Figure 8) is met with a safety factor of one to three.

Figure 6 shows the relative time differences of the Mediterranean Sea chain and the Norwegian Sea chain with respect to UTC of the Istituto Elettrotecnico Nazionale (IEN) of Turin, Italy and UTC of the USNO. From this figure one can calculate the UTC time difference between IEN and the USNO and between the two Loran-C chains as shown in Figure 7. It should be pointed out that these calculations were made on the assumption that the propagation delays are constant for the time of observation between the monitoring stations and the Loran-C transmitters and between the slave stations and their master stations. This assumption is reasonable for a short period of time (days), and is under question for a longer period of time (months or longer).

LONG-TERM TIME STABILITY OF LORAN-C CHAINS

Figure 8 shows the time differences of six of the eight Loran-C chains relative to the master clock of the U.S. Naval Observatory (USNO MC) as a function of time for about 900 days. Figures 9, 10, and 11 show the time difference of nine individual Loran-chains relative to the USNO MC. Figure 9 shows the present behavior of time controlled Loran-C chains. Figures 10 and 11 show the progress of implementing the time control of a Loran-C chain. In Figure 11, the performance of the West Coast Loran-D chain, which was recently implemented, is also given.

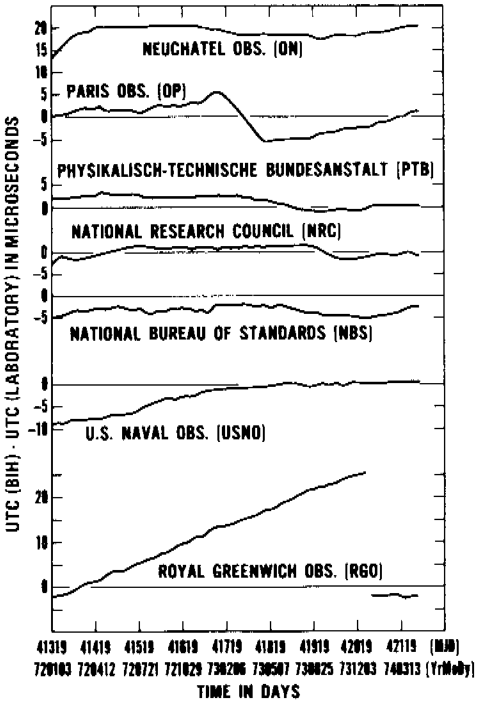

Fig. 4—Coordinated Universal Time (UTC) Scale of Individual Laboratory Relative to UTC (BIH)

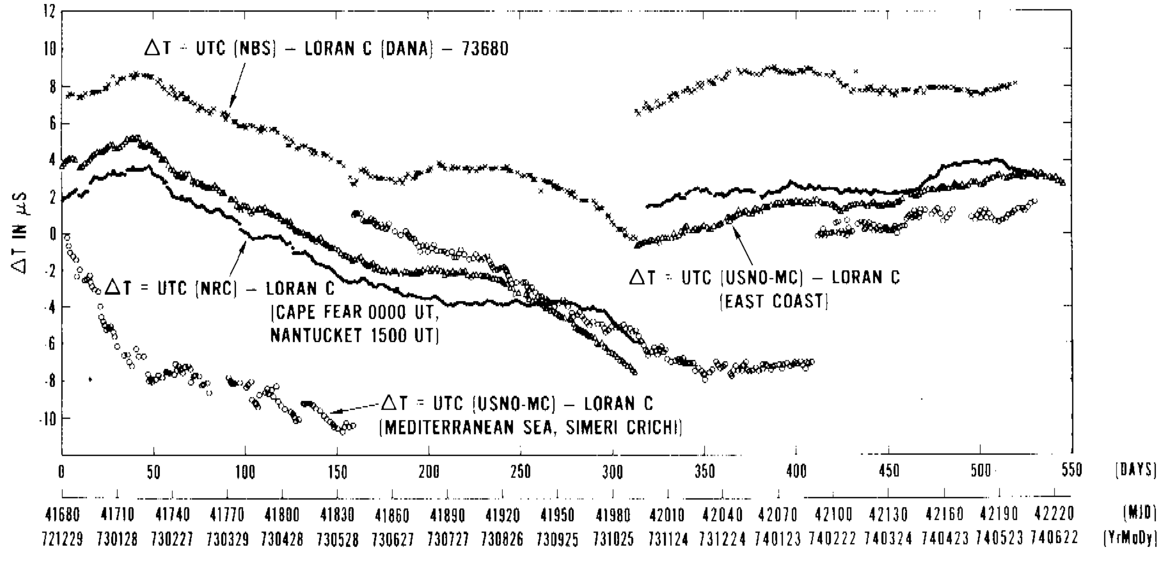

Fig. 5—Comparison of Coordinated Universal Time Scales Via Loran-C East Coast Chain (Data Source -- National Bureau of Standards' Special Publication 236, U.S. Naval Observatory's Daily Phase Values and Time Differences Series 4, and Canadian National Research Council's Loran-C Measurements)

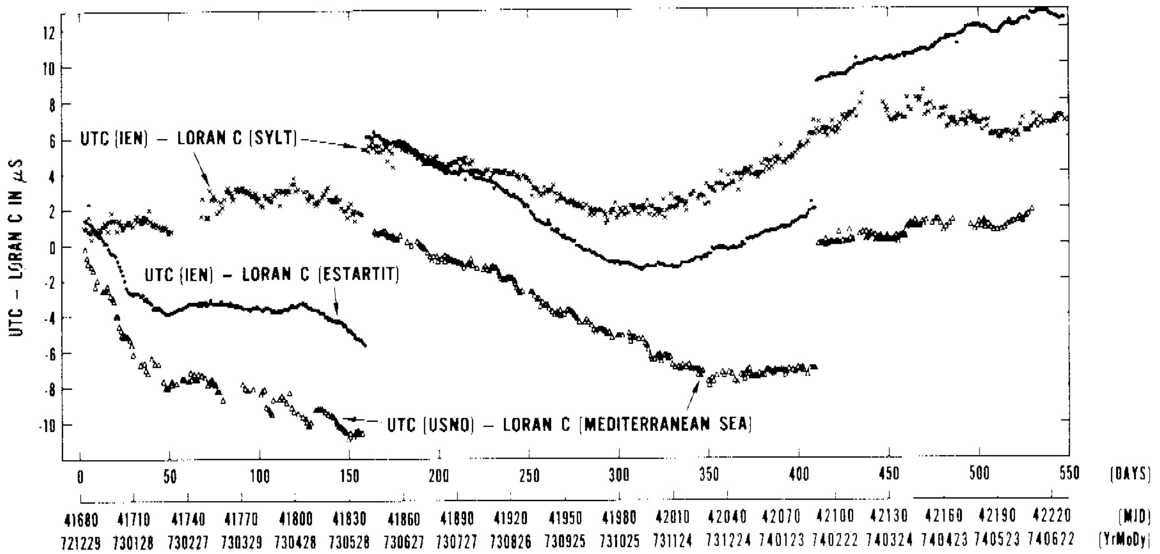

Fig. 6—Comparison of Coordinated Universal Time Scales Via Loran-C Mediterranean Sea and Norwegian Sea Chains (Data Source -- Circulars of Istituto Elettrotecnico Nazionale -- Tourin, Italy and U.S. Naval Observatory's Daily Phase Values and Time Differences Series 4)

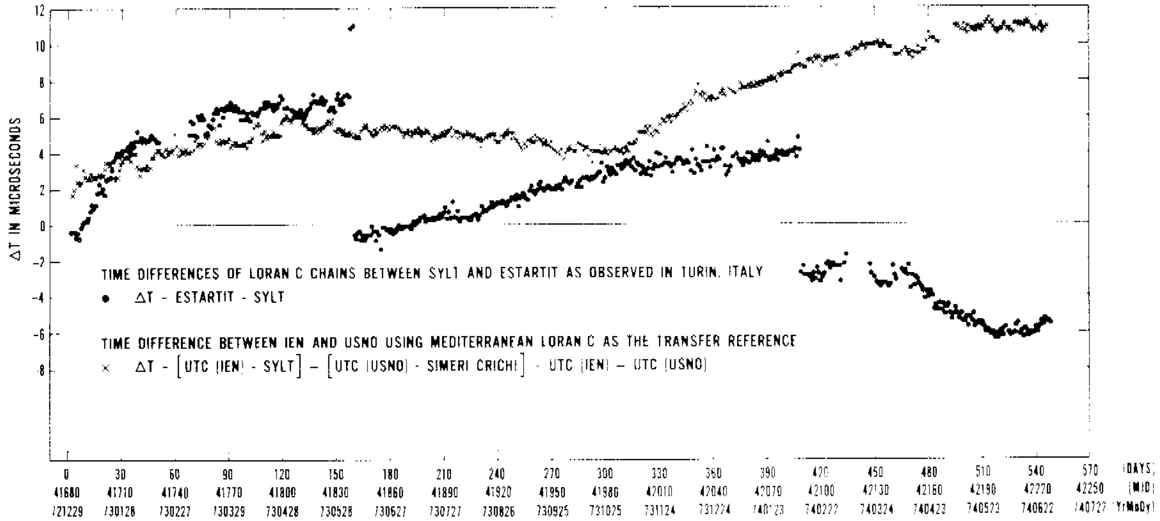

Fig. 7—Comparison of Time Transmissions of Loran-C Chains Via an Independent Monitoring Laboratory (IEN) and of Coordinated Universal Time Scales of Two Independent Laboratories Via Multiples of Loran-C Chains

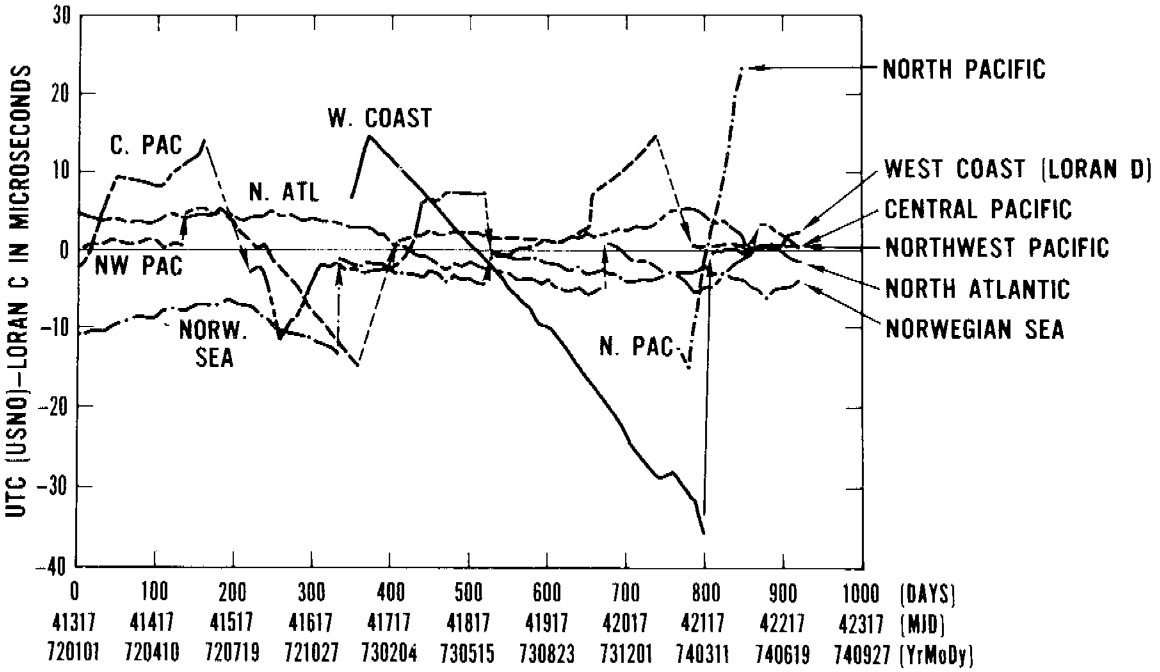

Fig. 8—Performance of Loran-C Transmissions as a Precise Time Reference Signal (Data Source -- U.S. Naval Observatory Daily Phase Values and Time Differences Series 4)

For convenience some reference information on Loran-C and Loran-D is given in Appendix B of this report. Table B-1 gives the stations of the nine Loran-chains, and their repetition rates. Users of Loran-C are advised that the repetition rate for each chain has been changed from time to time since 1970. This is done to avoid cross chain interference of the Loran-C tranmissions and to identify the chains. Table B-2 gives the basic group repetition rates. Table B-3 gives the Loran-C group period in microseconds for basic and specific rates. Table B-4 gives the phase reversal coding sequence of the eight pulses within each group for the master and slave stations.

USE OF UTC AND LORAN-C

Based on the excellent performance of the clocks maintained by the national laboratories and observatories it is obvious that special facilities and supporting personnel are required to maintain a constant time scale in addition to an ensemble of highly accurate clocks. This is particularly true if the time scale is to be compared to another such as UTC (BIH) or TAI (BIH). Users who have requirements for clock time accurate to a few microseconds or better relative to a national time standard such as UTC (USNO MC) or UTC (NBS) must use

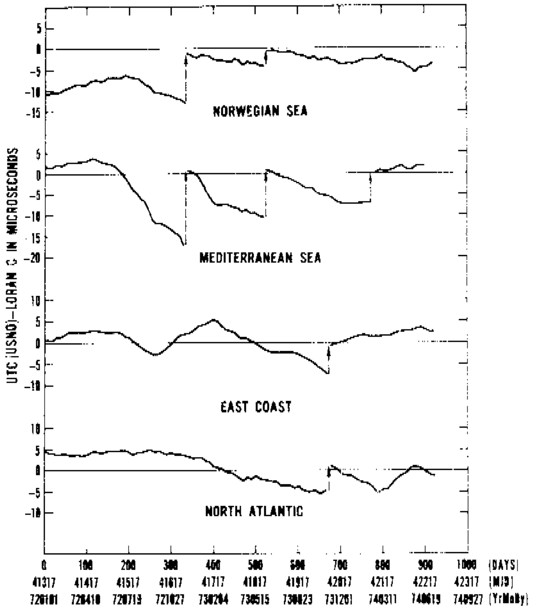

Fig. 9—Performance of Individual Loran-C Chains Relative to U.S. Naval Observatory Master Clock

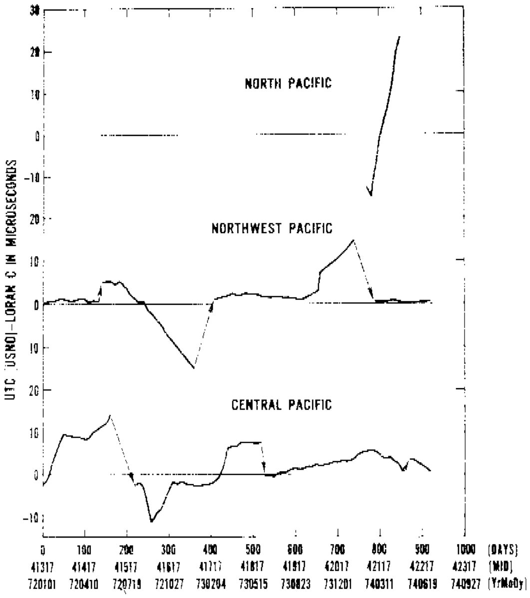

Fig. 10—Performance of Individual Loran-C Chains Relative to U.S. Naval Observatory Master Clock -- Continued from Figure 9

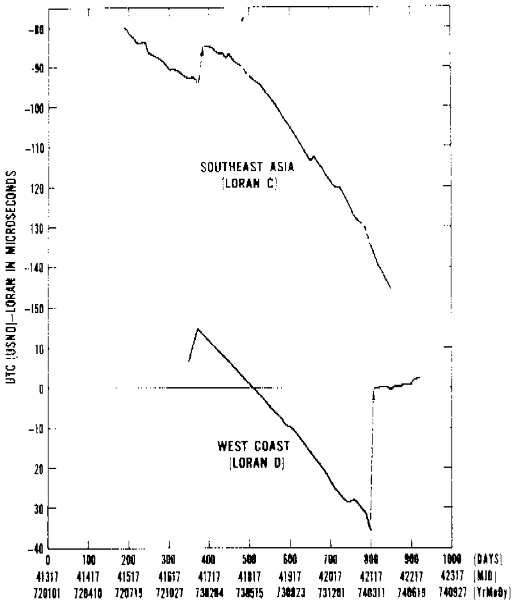

Fig. 11—Performance of Individual Loran-C Chains Relative to U.S. Naval Observatory Master Clock -- Continued from Figure 10

the corrections provided by the national time keeping agencies. This is true even for precise time interval users who may correlate periodicities or compare independent observations which were made over a long span of time.

The daily time corrections made to the Loran-C transmission are determined by real time measurements made by monitoring stations. In addition, portable clocks or satellite time transfer techniques are used to measure the clock differences between the monitoring stations and the USNO. From these clock measurements post corrections are occasionally generated to correct the Loran-C corrections. New users of precise time must pay special attention to the proper use of the circulars, bulletins, or announcements issued by the national laboratories.

TYPICAL NASA TRACKING STATION CLOCK PERFORMANCE

NASA Spaceflight Tracking Data Network (STDN) is equipped with cesium atomic frequency standards, VLF receivers, Loran-C receivers and WWV receivers. Each station has at least one cesium beam tube standard with automatic backup to a rubidium gas cell standard and a crystal oscillator standard[8] in the event of a failure. Some sites have two cesium standards -- one prime and one backup. Eventually, by late 1975, all sites will have two cesium standards. Each station also has either a dual redundant or a triple redundant majority logic time code generating system. The timing systems have many and varied frequency, pulse, and time code outputs to meet station frequency and time requirements.

The station clock is rated with respect to the USNO MC via a naval communications VLF transmission such as the VLF station NAA at Cutler, Maine. When it has been determined that the frequency of the station clock deviates by more than $\pm 1 \times 10^{-12}$, for three months or longer, the station timing engineer is directed by the network operation engineer in charge of timing to change the clock frequency by an amount to minimize the deviation. A typical performance record is shown in Figure 12 which shows the phase difference between the Canary Island station clock relative to the USNO MC (labeled as time advance) as a function of time for fiscal year 1974. The phase difference measurement is actually made by using the NAA VLF station as the transfer frequency reference. When the VLF phase suffered a phased jump, as indicated by the crosses which are not in coincidence with the circles, the phase is corrected. If the VLF phase record is discontinuous, e.g., due to propagation anomalies, the phase jump can often be measured and corrected as shown by the circles. If the discontinuity is due to equipment failure, the phase jump can only be estimated. Since a phase jump can be several cycles, the actual measured VLF phase differences often fall outside the range of the scale ±100 microseconds. The fact that the phase of a VLF signal is not continuous is a major shortcoming for time transmissions. The use of dual VLF for time transmission is an approach to remove or to reduce the phase jumps.

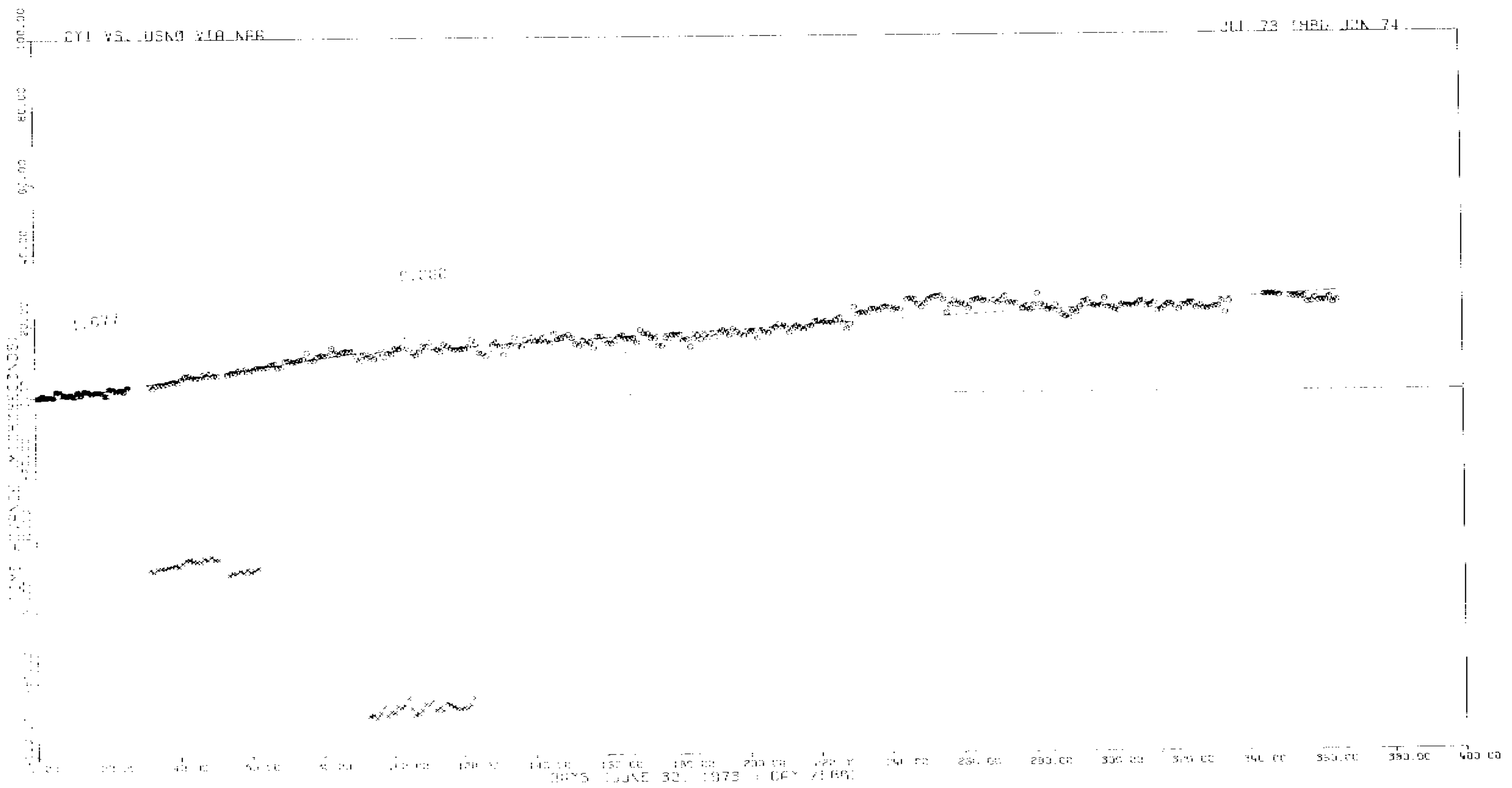

Fig. 12—Frequency Comparison and Rating of NASA Tracking Station Clock at Canary Island (CYI) Relative to U.S. Naval Observatory Master Clock Via Naval Communication VLF Station NAA, Cutler, Maine

The station clock is synchronized via a standard time signal emission, such as WWV, for coarse time. The fine time is obtained via a Loran-C signal. Those stations which are within the range of the groundwave propagated signals at 100 kHz, can usually maintain their clocks to ±20 microseconds or better depending on the operation procedure and geographical location relative to a Loran-C chain. The curves in figures 12 through 15 represent the time difference and the circles, the phase difference. The least square fit of the phase difference of a segment of data is the frequency difference between the station cesium frequency standard and the USNO MC. Figure 13 shows the Canary Island (CYI) station clock relative to USNO via Estartit, a slave station of the Mediterranean Sea chain. It is interesting to compare these frequency differences as measured via NAA (Figure 12) and Loran-C Mediterranean Sea chain (Figure 13). The agreement is within 0.5×10^{-12}.

The best performance of a NASA station clock maintained to the USNO MC is that of the station at Merritt Island, Florida (MIL) as shown in Figure 14. For the data shown it actually surpasses the performance of the Loran-C East Coast chain. While the East Coast chain was used as the transfer time reference, the fact that the frequency of the station clock was not adjusted probably accounts for its superior performance.

When a NASA station is located outside the range of the groundwave propagated signal of a Loran-C chain such as Carnarvon in northwest Australia, the skywave propagated signal was used. For convenience in calculation it was assumed that the same mode of propagation took place for the path between the station and the transmitter. Figure 15 shows the station clock performance at Carnarvon relative to USNO MC via the 5th hop propagated from Iwo Jima of the Northwest Pacific Loran-C chain. It can be seen from this figure that the Carnarvon station clock was maintained to within 75 microseconds of USNO MC for the year shown.

Although extensive analysis of the performance of the NASA's station clocks cannot be presented in this paper, enough evidence has been presented to the users for the need of the corrections to frequency or time transfer reference signals if they are to be used to maintain the user's clocks. Some evidence was also presented to support the body of opinion that the best performance of a clock is achieved by fewer corrections or perturbations.

The author wishes to express his appreciation to Mr. John K. Jones, GSFC Network Operation Engineer in charge of timing for implementing the computer data reduction and analysis of the NASA station clocks relative to USNO master clock and for providing the graphs to the author for publication. He also wishes to acknowledge the assistance of Leslie Lobel who plotted Figures 1 through 11 during the summer of 1974.

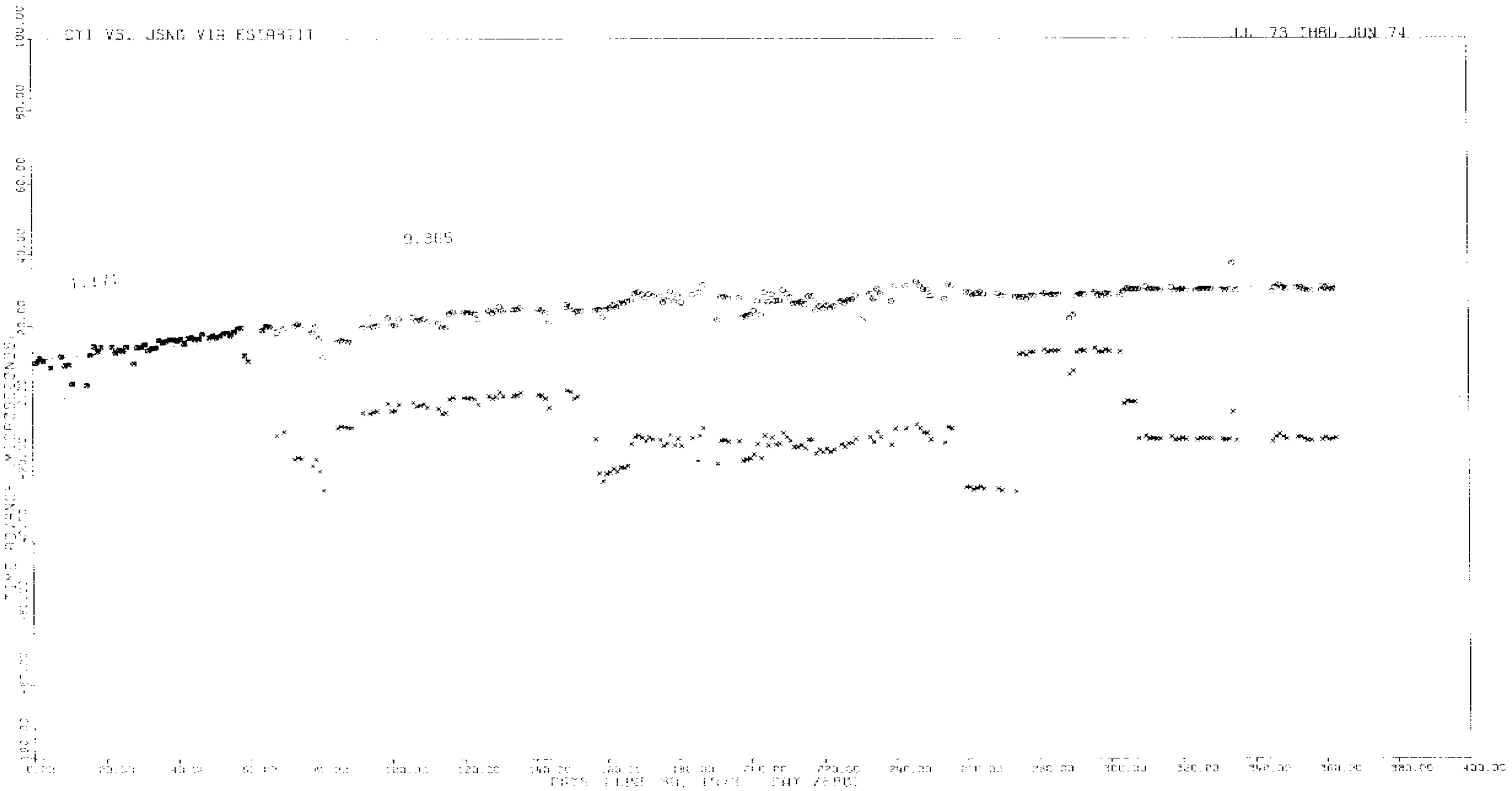

Fig. 13—Time Comparison and Control of NASA Tracking Station Clock at Canary Island (CYI) Relative to U.S. Naval Observatory Master Clock Via Loran-C Mediterranean Sea Chain

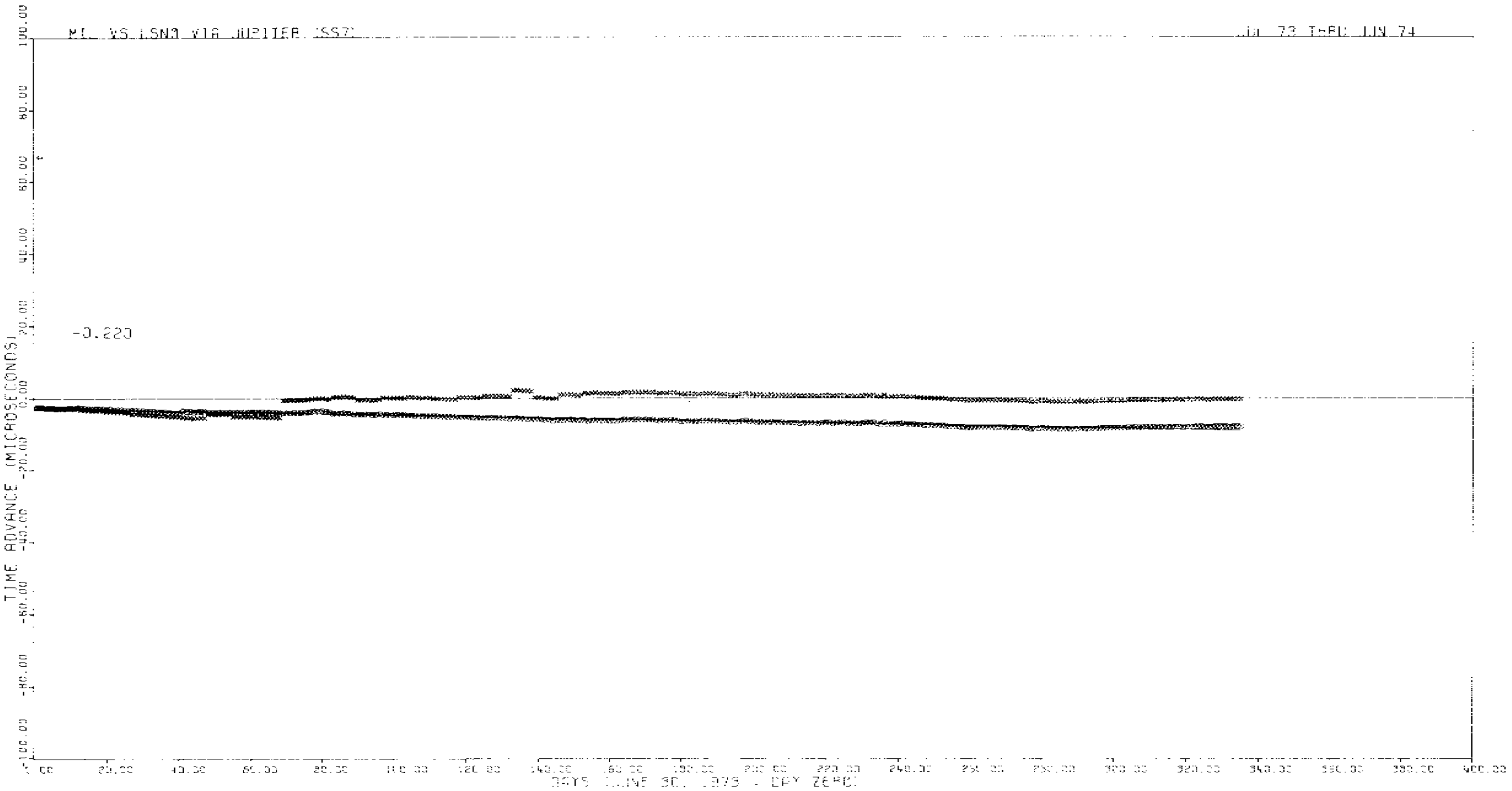

Fig. 14—Performance of NASA Tracking Station Clock at Merritt Island, Florida (MIL) Relative to U.S. Naval Observatory Master Clock Via Loran-C East Coast Chain (This is the Best Performance of a NASA Tracking Station Clock Among Twenty)

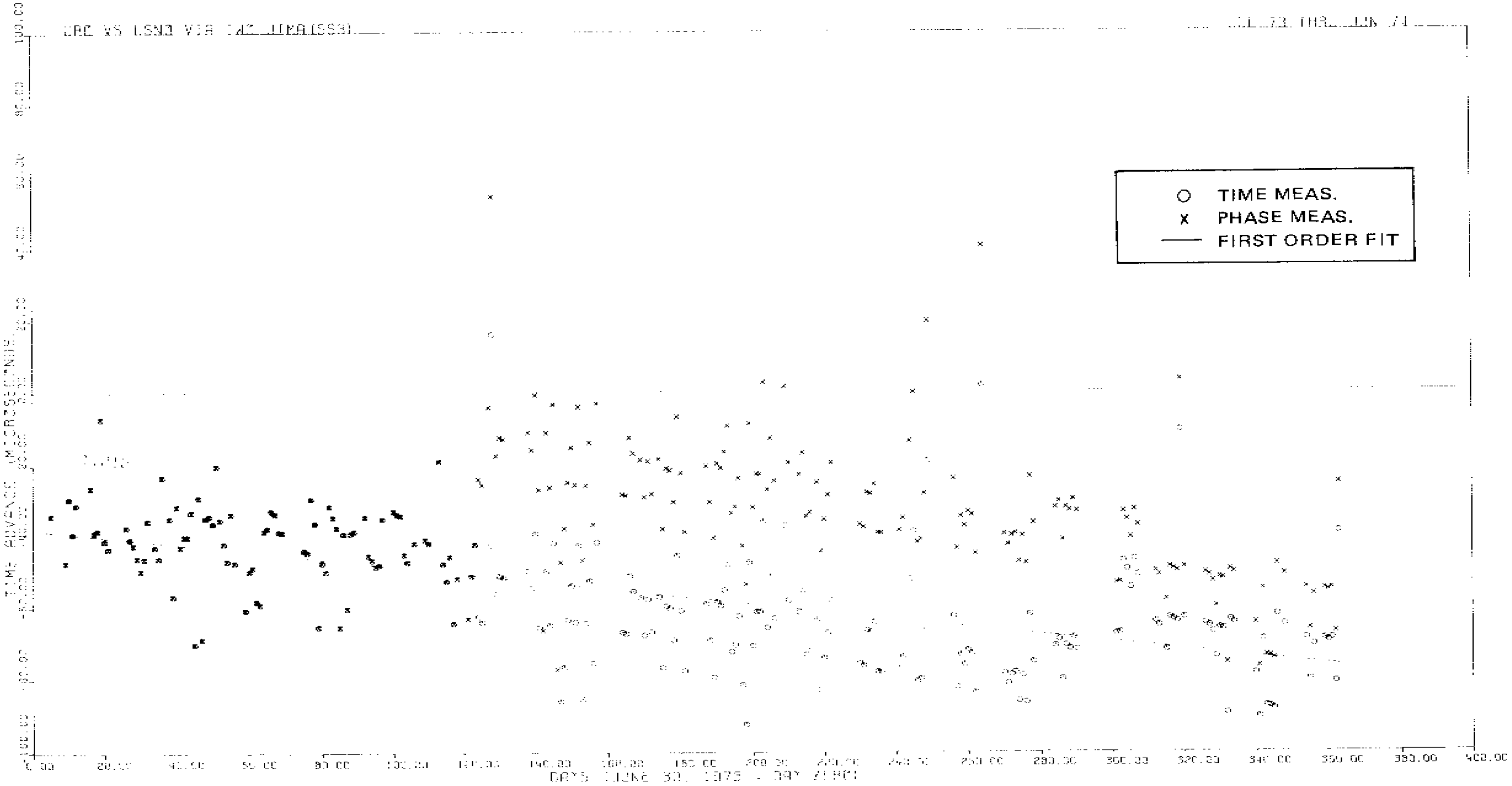

Fig. 15—Time Comparison and Control of NASA Tracking Station Clock at Carnarvon, Australia (CRO) Relative to U.S. Naval Observatory Master Clock Via a Skywave Propagated Signal From Loran-C Northwest Pacific Chain

REFERENCES

1. In a broad sense any radio frequency transmission which broadcasts time information may be considered as a time signal emission. In a strict sense only those stations which conform with the recommendations of the International Radio and Consultative Committee (CCIR) are considered as the standard frequency and time signal emissions.

2. A. R. Chi, "A Survey Paper on Atomic Frequency Standards Used in the United States," NATO Conference of Experts on Electronics, Paris, France, Sept. 1962; also W. E. Fizell, On The Determination of Universal Time and The Use of U. S. Naval Observatory Time Service Bulletins, Notices, and Announcements, GSFC X-Document, X-521-70-108.

3. G. M. R. Winkler, R. G. Hall, D. B. Percival, "The U. S. Naval Observatory Clock Time Reference and The Performance of a Sample of Atomic Clocks," Metrologia, 6, 4 p. p. 126-134, October 1970.

4. H. M. Smith, "International Time and Frequency Coordination" Proc. IEEE 60, 5, p. p. 479-487, May 1972.

5. J. T. Henderson, "The Foundation of Time and Frequency in Various Countries," Proc. IEEE, 60, 5, p. p. 487-493, May 1972.

6. A. R. Chi and H. S. Fosque, "A Step in Time Changes in Standard-Frequency and Time-Signal Broadcasts -- January, 1972" IEEE Spectrum 9, 1, p. p. 82-86, January 1972. Also NASA Technical Note, NASA TN D-7065, January 1973.

7. Private communication with J. A. Barnes of NBS.

8. Cesium beam standards are Hewlett-Packard's models 5060, 5061A, and 5061A with option 004 high performance cesium beam tube. Rubidium gas cell standards are Varian Associates' Model R-20 and Tracor Model 304D. Crystal oscillators are Hewlett-Packard's Model 106 and Sulzer's Model A5.

APPENDIX A

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

28 AUGUST 1974

DAILY PHASE VALUES AND TIME DIFFERENCES SERIES 4 NO. 395

REFERENCES: (A) TIME SERVICE INFORMATION LETTER OF 15 AUGUST 1973
(B) TIME SERVICE ANNOUNCEMENT, SERIES 9, NO. 36 (LORAN-C)
(C) DAILY PHASE VALUES AND TIME DIFFERENCES, SERIES 4, NO. 389 (LORAN-D)
(D) DAILY PHASE VALUES AND TIME DIFFERENCES, SERIES 4, NO. 195 (TV)

THE TABLE GIVES: UTC(USNO MC) - TRANSMITTING STATION UNIT = ONE MICROSECOND

*MEASURED BY USNO TIME REFERENCE STATIONS WITHIN GROUND WAVE RANGE BUT CORRECTED TO REFER TO USNO MASTER CLOCK.

**COMPUTED FROM DIFFERENTIAL PHASE DATA PROVIDED BY THE U.S. COAST GUARD STATIONS OPERATING ON THE NORTH ATLANTIC REPETITION RATE AND FROM USNO MEASUREMENTS.

FREQUENCY KHZ (UTC)	MJD	LORAN-C* SS3 NORTHWEST PACIFIC 100	LORAN-C* S1 CENTRAL PACIFIC 100	LORAN-C SS7 EAST COAST U.S.A. 100	LORAN-C** SL3 NORWEGIAN SEA 100	LORAN-C** SL1 MEDITERRANEAN SEA 100	LORAN-C** SL7 NORTH ATLANTIC 100
AUG. 14	42273	-3.5	-	0.6	-3.8	1.2	-5.1
15	42274	-3.5	-	0.5	-3.7	1.4	-5.1
16	42275	-3.6	-	0.4	-3.8	1.1	-5.3
17	42276	-3.5	-	0.4	-3.7	1.3	-5.4
18	42277	-3.5	-	0.3	-3.6	1.3	-5.5
19	42278	-3.6	-	0.3	-3.5	1.4	-5.3
20	42279	-3.6	-	0.2	-3.9	1.2	-5.7
21	42280	-3.6	-	0.2	-3.7	1.2	-5.6
22	42281	-3.7	-	0.1	-3.7	1.1	-5.6
23	42282	-3.8	-	0.0	-3.4	-	-5.4
24	42283	-3.7	-	-0.2	-3.7	-	-5.8
25	42284	-3.7	-	-0.2	-3.8	-	-5.9
26	42285	-3.7	-	-0.2	-3.9	-	-6.0
27	42286	-3.8	-	-0.3	-3.6	-	-6.0
28	42287	-3.6	-	-0.3	-3.5	-	-5.9

FREQUENCY KHZ (UTC)	MJD	LORAN-C** SH3 SOUTHEAST ASIA 100	LORAN-C* SH7 NORTH PACIFIC 100	LORAN-D S7 WEST COAST U.S.A. 100	6 OMEGA ND 10.2 6,000+	7 OMEGA ND 13.1 6,000+	5 OMEGA ND 13.6 6,000+
AUG. 14	42273	-162.3	-	4.4	427	428	428
15	42274	-162.4	-	4.3	428	429	429
16	42275	-162.1	-	4.4	428	429	429
17	42276	-162.5	-	-	428	430	431
18	42277	-162.9	-	-	428	430	431
19	42278	-	-	4.5	428	429	430
20	42279	-	-	4.6	-	-	-
21	42280	-	-	4.8	-	-	-
22	42281	-	-	4.7	425	426	427
23	42282	-	-	4.7	426	426	427
24	42283	-	-	-	425	426	427
25	42284	-	-	-	425	426	427
26	42285	-	-	5.0	426	427	428
27	42286	-	-	5.1	426	427	428
28	42287	-	-	5.1	425	425	428

FREQUENCY KHZ (UTC)	MJD	1 OMEGA T 13.6 11,000+	4 GBR 16.0 19,000+	2 NAA 17.8 3,000+	3 NLK 18.6 12,000+	8 NBA 24.0 11,000+	WASHINGTON, DC WTTG CHANNEL 5 EMITTED
AUG. 22	42281	627	518	224	589	-	3.9
23	42282	627	517	223	589	-	3.9
24	42283	627	517	223	589	073	3.9
25	42284	628	517	223	588	073	-
26	42285	628	518	224	589	072	3.8
27	42286	628	516	222	589	071	3.8
28	42287	627	518	223	589	070	-

DAILY PHASE VALUES AND TIME DIFFERENCES SERIES 4, NO. 395 (CONTINUED)

			NATIONAL TELEVISION NETWORKS					
			NBC 19:25:00 UT	NBC 19:31:00 UT	CBS 19:26:00 UT	CBS 19:32:00 UT	ABC 19:27:00 UT	ABC 19:33:00 UT
		MJD						
AUG.	22	42281	27,271.2	20,248.6	6,831.2	33,175.2	9,238.8	2,216.3
	23	42282	7,292.7	3,215.1	23,088.8	16,066.1	25,532.4	18,509.9
	24	42283	10,514.9	3,492.3	29,832.3	22,792.5	26,978.6	19,820.0
	25	42284	2,452.0	28,659.2	22,240.1	15,219.4	10,652.7	3,493.6
	26	42285	20,856.2	1,126.1	5,131.0	-	6,154.5	-
	27	42286	24,450.0	17,426.6	21,388.1	14,363.4	22,448.5	15,428.0
	28	42287	11,008.6	406.2	4,277.1	30,621.0	5,375.3	31,719.5

NOTES:

(1) PROPAGATION DISTURBANCES WERE OBSERVED NEAR THE FOLLOWING TIMES:
23 AUG. 1135/3
24 AUG. 1430/3
27 AUG. 1855/3
28 AUG. 1655/4.

(2) NAVY STATION OFF-AIR TIMES:
NBA 25 AUG. 1127 TO 1128 UT
1433 TO 1434 UT
1910 TO 1912 UT

(3) (SH3) SOUTHEAST ASIA LORAN-C
12 AUG. -161.5
13 AUG. -160.5

(4) (SL3-W) NORWEGIAN SEA LORAN-C SLAVE SYLT, GERMANY WAS OFF THE AIR 0950 TO 1047 UT 27 AUG.

(5) (S1-X) CENTRAL PACIFIC LORAN-C SLAVE UPOLU POINT, HAWAII IS SCHEDULED TO BE OFF THE AIR 1730 TO 0430 UT DAILY COMMENCING 1730 UT 27 AUG. AND ENDING 0430 UT 1 SEP. AND FIVE-MINUTE PERIODS DAILY AT 1730, 2200, 2300, 0200, AND 0430 UT COMMENCING 1730 UT 1 SEP. AND ENDING 0435 UT 15 SEP.

(6) (SS3-M) NORTHWEST PACIFIC LORAN-C MASTER IWO JIMA IS SCHEDULED TO BE OFF THE AIR 0130 TO 0430 UT 29 AUG.

(7) (SS7) EAST COAST LORAN-C CHAIN IS SCHEDULED TO BE DECREASED IN FREQUENCY BY APPROXIMATELY 8.0 PARTS IN TEN TO THE THIRTEENTH AT 1600 UT 6 SEP.

(8) (SL7) NORTH ATLANTIC LORAN-C CHAIN IS SCHEDULED TO BE DECREASED IN FREQUENCY BY APPROXIMATELY 1.0 PART IN TEN TO THE TWELFTH AT 1600 UT 6 SEP.

(9) OMEGA STATIONS OFF-AIR TIMES:
NORTH DAKOTA 24 AUG. 0502 TO 0504 UT
0526 TO 0535 UT
0641 TO 0643 UT
2217 TO 2220 UT
25 AUG. 0435 TO 0437 UT
0452 TO 0454 UT
0513 TO 0515 UT
0842 TO 0844 UT
0921 TO 0923 UT
0929 TO 0931 UT
0948 TO 0950 UT
1048 TO 1050 UT
1257 TO 1259 UT
1418 TO 1420 UT
1710 TO 1712 UT
1817 TO 1819 UT
1918 TO 1919 UT
TRINIDAD 28 AUG. ABOUT 1005 TO 1015 UT

BUREAU INTERNATIONAL DE L'HEURE
(B.I.H.)
61, Avenue de l'Observatoire
75014 - PARIS

Circular D84
Paris, 1973 November 5

1 - UNIVERSAL TIME AND COORDINATES OF THE POLE

Date (0h UT) 1973	MJD	smoothed values x 0".0001	 y 0".0001	 UT2-UTC 0.0001s	 UT1-UTC 0.0001s	raw values x 0".0001	 y 0".0001	 UT1-UTC 0.0001s	UT1-TAI s
Sept. 4	41 929	+ 8	+340	+ 414	+ 645	- 5	+349	+ 597	-11.9355
9	934	+ 16	+341	+ 254	+ 505	- 6	+334	+ 521	9495
14	939	+ 25	+342	+ 94	+ 360	+ 26	+334	+ 359	9640
19	944	+ 33	+344	- 65	+ 213	+ 53	+337	+ 206	9787
24	949	+ 41	+346	- 223	+ 63	+ 35	+342	+ 86	9937
29	954	+ 48	+347	- 379	- 89	+ 59	+352	- 102	-12.0089
Oct. 4	959	+ 55	+348	- 533	- 243	+ 62	+342	- 245	0243

TAI-UTC is exactly 12s since 1973 Jan. 1st, 0h UTC.

2 - EMISSION TIME OF TIME SIGNALS, for Sept. 1973.

a - Time signals emitted in the UTC time scale, within ± 0.0002 s

CHU, DAM, DAN, DAO, DCF77, DGI, DIZ*, FFH, FTA91, FTH42, FTK77, FTN87, GBR, HBG, IAM, IBF, JJY, LOL, MSF, NSS(hf), OMA, PPE*, RWM, (and other signals from USSR), VNG, WWV, WWVB, WWVH, ZUO.
* DIZ : irregularities on 1973 Sept. 25.
* PPE : corrigendum : |UTC-PPE| < 0.0002s since, at least, January 1973.

b - Other time signals (unit : 0.0001s) : UTC-OLB5 = + 8.

3 - COORDINATED UNIVERSAL TIME

a - From LORAN-C and Television pulses receptions

Date 1973 MJD	Sept. 4 41 929	Sept. 14 41 939	Sept. 24 41 949
Laboratory i	UTC-UTC(i)	(unit : 1 µs)	
PTB (Braunschweig)	- 1.0	- 0.9	- 0.9
USNO (Washington) (USNO MC)	- 0.1	+ 0.1	+ 0.1
OP (Paris)	- 3.7	- 3.6	- 3.5
NBS (Boulder)	- 3.6	- 3.8	- 4.1
RGO (Herstmonceux)	+ 22.1	+ 22.3	+ 22.7
NRC (Ottawa)	+ 1.0	+ 0.6	- 0.1
FOA (Stockholm)	+ 47.9	+ 47.4	+ 46.9
ON (Neuchâtel)	+ 17.9	+ 17.8	+ 17.8
IEN (Torino)	- 4.9	- 4.5	- 4.5
NPL (Teddington)	- 30.4	- 30.7	- 30.9
OMSF (San Fernando)	+ 30.6	+ 34.1	+ 37.4
TP (Praha)	- 15.7	- 15.7	- 15.8

P. T. O.

b - From clock transportations (unit : 1 µs)

From "Daily Phase Values", Series 4, N° 349, USNO

National Physical Laboratory, Teddington, Middlesex, England :
1973 Sept. 17 (MJD = 41942.3), UTC(USNO MC)-UTC(NPL) = - 32.7 ± 0.2

Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, England :
1973 Sept. 17 (MJD = 41942.6), UTC(USNO MC)-UTC(RGO) = + 19.2 ± 0.2

Paris Observatory, Paris, France :
1973 Sept. 26 (MJD = 41951.7), UTC(USNO MC)-UTC(OP) = - 6.7 ± 0.2

Note : A discrepancy of about 3 µs appears between the data of the clock transportations and those obtained by LORAN-C, between America and Europe. Investigations are in progress.

4 - INDEPENDENT LOCAL ATOMIC TIME SCALES AT(i)

The value of TAI-AT(i) are given for the laboratories contributing in the formation of TAI. They are obtained from LORAN-C pulses receptions.

Date 1973 MJD	Sept. 4 41 929	Sept. 14 41 939	Sept. 24 41 949
Laboratory i	TAI-AT(i)	(unit : 1 µs)	
PTB (Braunschweig)	- 366.4	- 366.3	- 366.2
USNO (Washington) (1)	- 34 399.7	- 34 399.6	- 34 399.6
F (Paris) (2)	- 60.2	- 60.2	- 60.2
NBS (Boulder)	- 45 140.3	- 45 139.2	- 45 138.1
RGO (Herstmonceux) (3)	+ 22.1	+ 22.3	+ 22.7
NRC (Ottawa)	+ 1.0	+ 0.6	- 0.1
ON (Neuchâtel)	+ 17.9	+ 17.8	+ 17.8

(1) AT(USNO) is designated by A1(Mean) by USNO
(2) F denotes Commission Nationale de l'Heure, Paris
(3) AT(RGO) is designated by GA2 by RGO

5 - INFORMATIONS

a - Introduction of a positive leap second in UTC

A positive leap second will occur at the end of December 1973. The sequence of dates of the UTC second markers will be, as recommended by Annex I of the CCIR Report 517 :

31 Dec. 1973 , $23^h59^m59^s$
31 Dec. 1973 , $23^h59^m60^s$
1 Jan. 1974 , $0^h\,0^m\,0^s$.

TAI-UTC will be + 13s after the introduction of the leap second.

Circular n. 26

IEN - Istituto Elettrotecnico Nazionale - Turin (Italy)

VLF, LF AND LORAN C SIGNALS RECEIVED AT IEN

REFERENCE: HP 5061 A Cesium Standard
UTC(IEN) - SIGNAL
microseconds

DATE MARCH 1974	M.J.D.		NAA	GBR	MSF	ESTARTIT	SYLT	IAM
		kHz	17.8	16.0	60.0	100.0	100.0	5,000
		UT	1400	1400	1400	1400	1400	0800
			9,000+	9,000+	1,000+			x10^{3}
1	42107		891.0	994.5	671.5	+9.4	+7.0	-
2	8		891.0	994.0	689.0	+9.5	+7.2	-
3	9		887.0	992.5	673.0	+9.6	-	-
4	10		885.0	992.0	675.0	+9.6	+7.2	-
5	11		886.0	992.0	655.0	+9.8	+7.4	-
6	12		885.5	992.0	625.0	+10.2	+7.0	-
7	13		-	-	-	+9.9	-	-
8	14		888.0	994.0	624.5	+9.9	+7.7	-
9	15		891.0	994.0	593.0	+9.9	+8.2	-
10	16		888.0	993.5	609.0	+9.9	-	-
11	17		888.0	994.0	609.0	+10.0	-	-
12	18		887.5	995.5	592.0	+10.0	-	-
13	19		888.0	996.0	579.0	+10.1	-	1.8
14	20		889.0	996.0	579.0	+10.1	-	-
15	21		889.0	996.0	579.0	+10.1	-	1.9
16	22		890.0	995.5	581.0	+10.2	-	-
17	23		889.0	996.0	545.0	+10.2	-	-
18	24		890.0	996.0	528.0	+10.1	-	-
19	25		895.0	996.0	513.0	+10.1	-	-
20	26		893.0	996.5	482.0	+10.1	-	-
21	27		893.0	996.5	447.0	+10.1	+7.8	-
22	28		892.0	997.0	430.0	+10.2	+7.5	-
23	29		891.0	998.0	448.0	+10.2	+7.2	-
24	30		891.0	997.5	449.5	+10.2	+6.9	-
25	31		893.0	997.0	450.0	+10.3	+6.9	1.4
26	32		890.0	997.0	418.0	+10.2	+6.7	-
27	33		890.0	997.0	400.0	+10.1	+6.8	-
28	34		890.0	997.0	385.0	+10.2	+6.9	-
29	35		891.0	997.0	369.0	+10.3	+7.0	-
30	36		890.0	997.0	385.0	+10.3	+7.0	-
31	37		891.5	997.5	369.0	-	-	-

NATIONAL RESEARCH COUNCIL, OTTAWA, CANADA

LORAN C MEASUREMENTS

DATE	MJD	UTC(NRC)-LORAN C MICROSECONDS
740724	42252	1.40
740725	42253	1.33
740726	42254	1.28
740727	42255	1.25
740728	42256	1.29
740729	42257	1.32
740730	42258	1.27
740731	42259	1.09
740801	42260	0.99
740802	42261	0.94

THE ABOVE VALUES OF UTC(NRC)-LORAN C REFER TO EMISSION TIMES FROM THE MASTER STATION AT CAPE FEAR AT 00:00 UT. THE SIGNAL FROM THE NANTUCKET STATION IS MEASURED AT 15:00 UT ON WEEKDAYS ONLY, AND THE ABOVE VALUES ARE ALL LINEAR INTERPOLATIONS BETWEEN ADJACENT MEASUREMENTS.

PROPAGATION AND RECEIVER DELAY CORRECTIONS ARE BASED ON A PORTABLE CLOCK COMPARISON MADE ON MAY 21, 1974. THIS CORRECTION IS ASSUMED CONSTANT.

THE TIME SCALE UTC(NRC) IS BASED ON TWICE-WEEKLY CALIBRATIONS OF AN HP CLOCK ENSEMBLE IN TERMS OF CS III, THE 2.1 METRE NRC PRIMARY CESIUM BEAM FREQUENCY STANDARD.

APPENDIX B

Table B-1

LORAN-C DATA SHEETS

GENERAL SPECIFICATIONS AND NOTES

The latitude, longitude, and baseline lengths listed herein were furnished by the Defense Mapping Agency, Hydrographic Center and are based upon Mercury Datum 1960 - Center of Mass (CM). Appropriate geodetic satellite shifts have been added to relate these coordinates to the center of the earth.

The following parameters were used in the computations.

a. Signal propagation: Use the velocity of light in free space as 2.997942 x 10^8 meters/sec. and an index of refraction of 1.000338 at the surface for standard atmosphere.

b. Phase of the groundwave: As described in NBS Circular 573.

c. Conductivity: Sigma = 5.0 mhos/meter (seawater). Baseline electrical distance computations were made assuming a smooth, all seawater transmission path between stations.

d. Permittivity of the earth, esu: $e_2 = 80$ for seawater

e. Altitude in meters: $h_2 = 0$

f. Parameter associated with the vertical lapse of the permittivity of the atmosphere: a = 0.75

g. Frequency = 100 kHz

h. Fischer Spheroid (1960):

equatorial radius (a) = 6,378,166.000 meters

polar radius (b) = 6,356,784.283 meters

flattening (f) = (a-b)/a = 1/298.3

Inquiries pertaining to the LORAN-C system should be addressed to:

Commandant (GWAN-3)
U.S. Coast Guard
400 Seventh Street, S.W.
Washington, D.C., 20590

NOTE 1. Monitor station and/or antenna physically relocated. Positions given on old Data Sheets no longer valid. System control established using correlated numbers.

LORAN-C Data Sheet

Table B-1a

U. S. East Coast Chain - Rate SS7 (99, 300 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Carolina Beach N. C.	34-03-46. 50N 77-54-47. 29W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	TIP	1. 0 MW	Transmissions synchronized to UTC. Exercises operational control of chain. Control for W.
Jupiter, Florida	27-01-58. 85N 80-06-53. 59W	W Secondary	11, 000 μs 2695. 51 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Cape Race, Newfoundland	46-46-31. 88N 53-10-29. 16W	X Secondary	28. 000 μs 8389. 57 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	2. 0 MW	Host nation manned. Double-rated to NORLANT chain (SL7-Z).
Nantucket, Massachusetts	41-15-12. 29N 69-58-39. 10W	Y Secondary	49, 000 μs 3541. 33 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Dana, Indiana	39-51-08. 30N 87-29-12. 75W	Z Secondary	65, 000 μs 3560. 73 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Electronics Engineering Center, Wildwood, N. J.	38-56-58. 59N 74-52-01. 94W	T Secondary	82, 000 μs 2026. 19 μs	Cesium/ URQ-11	FPN-41, FPN-46 FPN-54 (Tmrs) FPN-42, FPN-44 (Xmtrs)	625 ft Tower	200 to 400 KW	Experimental station Not normally on air.
Bermuda U. K.	32-15-53. 18N 64-52-34. 27W	System Monitor		URQ-14	FPN-43 (Tmr)			Control for X & Y.
Eglin AFB, Florida	Note 1.	System Monitor		5C/5P	SPN-30 (Rcvr)			Control for Z.

LORAN-C Data Sheet

Table B-1b

North Atlantic Chain - Rate SL7 (79,300 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Angissoq, Greenland	59-59-17.19N 45-10-27.47W	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	625 ft Tower	360 KW	Host nation manned. Synchronized to UTC.
Sandur, Iceland	64-54-26.07N 23-55-28.41W	W Secondary	11,000 μs 4068.07 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	1.5 MW	Host nation manned. Double-rated to Norwegian Sea Chain (SL3Y).
Ejde, Faroe Islands	62-17-59.64N 07-04-26.55W	X Secondary	21,000 μs 6803.77 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	Host nation manned. Double-rated to Norwegian Sea Chain (SL3M).
Cape Race, Newfoundland	46-46-31.88N 53-10-29.16W	Z Secondary	43,000 μs 5212.24 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	2.0 MW	Host nation manned. Double-rated to U.S. East Coast Chain (SS7X).
Keflavik, Iceland	Note 1	System Monitor		URQ-14	SPN-30 (Revr)			Control for W & X. Exercises operational control of NORLANT chain.
St. Anthony, Newfoundland	Note 1	System Monitor			SPN-29 (Revr)			Host nation manned. Control for Z.

LORAN-C Data Sheet

Table B-1c

Norwegian Sea Chain - Rate SL3 (79,700 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Ejde, Faroe Islands	62-17-59.64N 07-04-26.55W	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	Host nation manned. Transmissions synchronized to UTC. Double-rated to NORLANT.
Bo, Norway	68-38-06.55N 14-27-48.46E	X Secondary	11,000 μs 4048.16 μs	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Host nation manned.
Sylt, Germany	54-48-29.24N 08-17-36.82E	W Secondary	26,000 μs 4065.69 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Sandur, Iceland	64-54-26.07N 23-55-20.41W	Y Secondary	46,000 μs 2944.47 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower.	1.5 MW	Host nation manned. Double-rated to NORLANT (SL7W).
Jan Mayen, Norway	70-54-51.63N 08-43-56.57W	Z Secondary	60,000 μs 3216.20 μs	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Host nation manned. Control for X.
Shetland Is., U. K.	(1) 60-26-25.27N 01-18-05.22W (2) 60-26-17.49N 01-18-19.08W	System Monitor		URQ-14	FPN-46 (Tmr)			Exercises operational control of chain. Control for W, Y, Z.
	(1) North antenna (2) South antenna							

LORAN-C Data Sheet

Table B-1d

Mediterranean Sea Chain - Rate SL1 (79.900 μsec) 26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Simeri Crichi. Italy	38-52-20.23N 16-43-06.39E	Master		Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	Temporarily synchronized to UTC.
Lampedusa, Italy	35-31-20.80N 12-31-29.96E	X Secondary	11,000 μs 1755.98 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	ATLS Station.
Targabarun, Turkey	40-58-20.22N 27-52-01.07E	Y Secondary	29.000 μs 3273.23 μs	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	625 ft Tower	250 KW	
Estartit. Spain	42-03-36.15N 03-12-15.46E	Z Secondary	47,000 μs 3999.76 μs	Cesium/ URQ-14	FPN-38 & FPN-54 (Tmrs) FPN-39 (Xmtr)	652 ft Tower	250 KW	
Rhodes. Greece	36-25 20.66N 28-09-31.92E	System Monitor		URQ-14	SPN-30 (Rcvr)			Control for X & Y.
Sardinia, Italy	39-10-51.26N 09-09-35.02E	System Monitor			SPN-29 (Rcvr)			Control for Z.

LORAN-C Data Sheet

Table B-1e

North Pacific Chain - Rate SH7 (59,300 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
St. Paul, Pribiloff Is., Alaska	57-09-12.10N 170-15-07.44W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	Controls X, Y, Z.
Attu, Alaska	52-49-44.40N 173-10-49.40E	X Secondary	11,000 μs 3875.17 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	
Port Clarence, Alaska	65-14-40.35N 166-53-12.95W	Y Secondary	28,000 μs 3068.97 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	1350 ft Tower	1.8 MW	
Sitkinak, Alaska	56-32-19.71N 154-07-46.32W	Z Secondary	42,000 μs 3284.83 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	400 KW	

LORAN-C Data Sheet

Table B-1f

Northwest Pacific Chain - Rate SS3 (99, 700 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Iwo Jima, Bonin Is.	24-48-04. 22N 141-19-29. 44E	Master		Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	3. 0 MW	Transmissions synchronized to UTC.
Marcus Is.	24-17-07. 79N 153-58-53. 72E	W Secondary	11, 000 μs 4284. 11 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-45 (Xmtr)	1350 ft Tower	3. 0 MW	
Hokkaido, Japan	42-44-37. 08N 143-43-16. 50E	X Secondary	30, 000 μs 6685. 12 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Gesashi, Okinawa, Japan	26-36-24. 79N 128-08-55. 99E	Y Secondary	55, 000 μs 4463. 21 μs	Cesium/ URQ-11	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Yap, Caroline Is.	09-32-45. 84N 138-09-55. 05E	Z Secondary	75, 000 μs 5746. 79 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-45 (Xmtr)	1000 ft Tower	3. 0 MW	
Saipan, Mariana Is.	15-07-47. 07N 145-41-37. 62E	System Monitor			SPN-30 (Rcvr)			Controls W & Z.
Fuchu, Japan	Note 1	System Monitor		Cesium	SPN-30 (Rcvr)			Controls X & Y. Time Service Monitor.

LORAN-C Data Sheet

Table B-1g

Central Pacific Chain - Rate S1 (49,900 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Johnston Is.	16-44-43.85N 169-30-31.63W	Master		Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	Transmissions synchronized to UTC.
Upolo Pt. Hawaii	20-14-50.24N 155-53-08.78W	X Secondary	11,000 μs 4972.38 μs	Cesium/ URQ-14	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	
Kure, Midway Is.	28-23-41.11N 178-17-29.83W	Y Secondary	29,000 μs 5253.08 μs	Cesium/ URQ-11	FPN-41 (Tmr) FPN-42 (Xmtr)	625 ft Tower	300 KW	
French Frigate Shoals	23-52-05.23N 166-17-19.60W	System Monitor		5C/5P	SPN-29 (Rcvr)			Controls X & Y.

LORAN-C Data Sheet

Table B-1h

Southeast Asia Chain - Rate SH3 (59700 μsec.)

26 March 1973

Station	Coordinates	Station Function	Coding Delay & Baseline Length	Major Equipment			Radiated Peak Power	Remarks
	Latitude & Longitude			Frequency Standards	LORAN-C Equipment	Xmiting Antenna		
Sattahip, Thailand	12-37-06.91N 100-57-36.58E	Master		Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Lampang, Thailand	18-19-34.19N 99-22-44.31E	X Secondary	11,000 μs 2183.11 μs	Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Con Son, RVN	08-43-26.18N 106-37-57.39E	Y Secondary	27,000 μs 2522.07 μs	Cesium/ Rubidium	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	
Tan My, RVN	16-32-43.13N 107-38-35.39E	Z Secondary	41,000 μs 2807.28 μs	Cesium/ URQ-14	FPN-46 (Tmr) FPN-44 (Xmtr)	625 ft Tower	400 KW	ATLS Station.
Udorn, Thailand	17-22-44.28N 102-47-12.48E	System Monitor		URQ-14	FPN-46 (Tmr)			Controls X, Y, Z.

U. S. Naval Observatory
Washington, D. C. 20390

Table B-1i

Daily Phase Values Series 4 17 October 1973

LORAN-D Transmissions No. 350

Experimental transmissions of precise time are available in the western part of the United States via the LORAN-D system. These transmissions are compatible with LORAN-C timing receivers. TOC tables and computed propagation time delays between user monitoring stations and any of the transmitting stations can be obtained from USNO.

The chain operates with a repetition rate of 49,300 microseconds. Coordinates and total emission delays are:

Glendale, Nevada (M)	36° 41' 17".6 N,	114° 38' 39".3 W	ON TOC
Palmdale, California (SA)	34° 32' 40".5 N,	117° 51' 17".2 W	12,255.0 Microsec.
Middlegate, Nevada (SB)	39° 17' 08".2 N,	118° 00' 53".9 W	24,380.0 Microsec.
Little Mountain, Utah (SC)	41° 14' 46".9 N,	112° 13' 25".4 W	36,830.0 Microsec.

Effective 23 Oct. 1973 the transmission schedule of the master station (M) will be 1800 to 0200 UT seven days a week and of the slave stations (SA, SB, SC) will be 2000 to 2400 UT seven days a week. Any changes in transmission schedule will be announced in Series 4.

U. S. Naval Observatory
Washington, D. C. 20390

17 July 1974

No. 389

Daily Phase Values and Time Differences Series 4

The coordinates and total emission delays of the west coast U. S. A. LORAN-D stations are as follows:

Master Lake Meade Aux, Nellis AFB, Nv	36° 14' 57".296N	114° 58' 57".459W	ON TOC
A Slave Pearblossom, Ca	34° 32' 40".453N	117° 51' 17".220W	12,077.30 μs
B Slave Fallon, Nv	39° 31' 00".402N	118° 54' 48".054W	24,675.14 μs
C Slave Little Mountain, Ut	41° 14' 46".924N	112° 13' 25".413W	37,019.61 μs
Monitor China Lake NWC, Ca	35° 41' 14".393N	117° 45' 16".168W	

The chain is maintained on time to the UTC time scale every day between the hours of 1900 and 2300 UT.

For more details see time service announcement Series 9, No. 86, of 19 Jul. 1974.

Table B-2

LORAN-C Basic Group Repetition Rates and Periods

Basic Designator	Rate (pps)	Corresponding Period for Specific Rate 0 (μsec)
SS	10	100,000
SL	12-1/2	80,000
SH	16-2/3	60,000
S	20	50,000
L	25	40,000
H	33-1/3	30,000

Table B-3

LORAN-C Group Repetition Periods for Specific Rates

Specific Rate	Basic Repetition Rate (μsec)					
	SS	SL	SH	S	L	H
0	100,000	80,000	60,000	50,000	40,000	30,000
1	99,900	79,900	59,900	49,900	39,900	29,900
2	99,800	79,800	59,800	49,800	39,800	29,800
3	99,700	79,700	59,700	49,700	39,700	29,700
4	99,600	79,600	59,600	49,600	39,600	29,600
5	99,500	79,500	59,500	49,500	39,500	29,500
6	99,400	79,400	59,400	49,400	39,400	29,400
7	99,300	79,300	59,300	49,300	39,300	29,300

Table B-4

LORAN-C Pulse Coding for Master and Slave Stations

Code Group	Pulse Phase in Degrees							
	1	2	3	4	5	6	7	8
M-1	0	0	180	180	0	180	0	180
M-2	0	180	180	0	0	0	0	0
S-1	0	0	0	0	0	180	180	0
S-2	0	180	0	180	0	0	180	180

APPENDIX C

REVISION OF UTC

As Adopted by The 13th Plenary Assembly of
The International Radio Consultative Committee (CCIR) in 1974
(Excerpted from CCIR Recommendation 460-1—effective date January 1, 1975)

ANNEX I

TIME SCALES

A. Universal Time (UT)

In applications in which an imprecision of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of UT which should be used:

UTO	is the mean solar time of the prime meridian obtained from direct astronomical observation;
UT1	is UTO corrected for the effects of small movements of the Earth relative to the axis of rotation (polar variation);
UT2	is UT1 corrected for the effects of a small seasonal fluctuation in the rate of rotation of the Earth;
UT1	is used in this document, since it corresponds directly with the angular position of the Earth around its axis of diurnal rotation. GMT may be regarded as the general equivalent of UT.

B. International Atomic Time (TAI)

The international reference scale of atomic time (TAI), based on the second (SI), as realized at sea level, is formed by the Bureau International de l'Heure (BIH) on the basis of clock data supplied by cooperating establishments. It is in the form of a continuous scale, e.g., in days, hours, minutes and seconds from the origin 1 January 1958 (adopted by the C.G.P.M. 1971).

C. Coordinated Universal Time (UTC)

UTC is the time-scale maintained by the BIH which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with (TAI) but differs from it by an integral number of seconds.

The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap-seconds) to ensure approximate agreement with UT1.

D. DUT1

The value of the predicted difference UT1-UTC, as disseminated with the time signals is denoted DUT1; thus DUT1 $\approx$ UT1 - UTC. DUT1 may be regarded as a correction to be added to UTC to obtain a better approximation to UT1.

The values of DUT1 are given by the BIH in integral multiples of 0.1 s.

The following operational rules apply:

1. Tolerances

1.1 The magnitude of DUT1 should not exceed 0.8 s.

1.2 The departure of UTC from UT1 should not exceed ±0.9 s.*

1.3 The deviation of (UTC plus DUT1) from UT1 should not exceed ±0.1 s.

2. Leap seconds

2.1 A positive or negative leap second should be the last second of a UTC month, but first preference should be given to the end of December and June, and second preference to the end of March and September.

2.2 A positive leap second begins at $23^h\ 59^m 60^s$ and ends at $0^h\ 0^m\ 0^s$ of the first day of the following month. In the case of a negative leap second, $23^h\ 59^m\ 58^s$ will be followed one second later by $0^h\ 0^m\ 0^s$ of the first day of the following month. (See Annex III.)

2.3 The BIH should decide upon and announce the introduction of a leap second, such an announcement to be made at least eight weeks in advance.

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*The difference between the maximum value of DUT1 and the maximum departure of UTC from UT1 represents the allowable deviation of (UTC + DUT1) from UT1 and is a safeguard for the BIH against unpredictable changes in the rate rotation of the Earth.

3. Value of DUT1

3.1 The BIH is requested to decide upon the value of DUT1 and its date of introduction and to circulate this information one month in advance.*

3.2 Administrations and organizations should use the BIH value of DUT1 for standard-frequency and time-signal emissions, and are requested to circulate the information as widely as possible in periodicals, bulletins, etc.

3.3 Where DUT1 is disseminated by code, the code should be in accordance with the following principles (except § 3.5 below):

—the magnitude of DUT1 is specified by the number of emphasized second markers and the sign of DUT1 is specified by the position of the emphasized second markers with respect to the minute marker. The absence of emphasized markers indicates DUT1 = 0;

—the coded information should be emitted after each identified minute.

Full details of the code are given in Annex II.

3.4 Alternatively, DUT1 may be given by voice or in Morse Code.

3.5 DUT1 information primarily designed for, and used with, automatic decoding equipment may follow a different code but should be emitted after each identified minute.

3.6 In addition, UT1-UTC may be given to the same or higher precision by other means, for example, in Morse Code or voice, by messages associated with maritime bulletins, weather forecasts, etc.; announcements of forthcoming leap-seconds may also be made by these methods.

3.7 The BIH is requested to continue to publish, in arrears, definitive values of the differences UT1-UTC, UT2-UTC.

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*In exceptional cases of sudden change in the rate of rotation of the Earth, the BIH may issue a correction not later than two weeks in advance of the date of its introduction.

ANNEX II

CODE FOR THE TRANSMISSION OF DUT1

A positive value of DUT1 will be indicated by emphasizing a number (n) of consecutive second markers following the minute marker from second markers one to second marker (n) inclusive; (n) being an integer from 1 to 8 inclusive.

$$DUT1 = (n \times 0.1)s$$

A negative value of DUT1 will be indicated by emphasizing a number (m) of consecutive second markers following the minute marker from second marker nine to second marker (8 + m) inclusive; (m) being an integer from 1 to 8 inclusive.

$$DUT1 = -(m \times 0.1)s$$

A zero value of DUT1 will be indicated by the absence of emphasized second markers.

The appropriate second markers may be emphasized, for example, by lengthening, doubling, splitting, or tone modulation of the normal second markers.

QUESTION AND ANSWER PERIOD

MR. DOHERTY:

I wanted to ask, on that first series of slides, what was the reference? Was it the average of all of the various standards? How various standards deviate. What was the base?

MR. CHI:

The base is BIH minus the different laboratories.

MR. DOHERTY:

I wanted to mention one other thing I forgot in connection with the history of Loran and that was that the first timing measurements were made on the Atlantic Missile range about 1960. When I went through the history of it, I forgot to mention it. They were made by taking two receivers down to the Atlantic Missile Range and showing that one locked, say, on Jupiter and one on the master could compare with one another within about a microsecond at that time down as far as the Ascension Island.

MR. ALLAN:

On that last slide I wonder if we might have that reshown. This is data received in Australia, correct?

MR. CHI:

Right.

MR. ALLAN:

On the slide, it seemed evident that there was some granulation in the data—you could see some lines parallel to the lines that you had drawn, (I wasn't sure what the vertical scale was). If the scale was about right it could be cycle ambiguity and that is one of the real problems with cycle identification because you could see some definite granulation lines that could perhaps seep into that.

MR. CHI:

Agreed.

MR. ALLAN:

Is that an explanation, I'm not sure.

MR. CHI:

You've got to remember this is long-term data processed through the computer as they are received. The intent is to show that if you do not do anything, you should be able to achieve about 75 microseconds.

MR. ALLAN:

You can see some lines.

MR. CHI:

The circles are time measurements, the crosses are frequency measurements. Now, I did not take the pains to point it out, I only mentioned that using the Loran-C you could measure both frequency and time. But if you do measure frequency from the phase measurement, sometimes in order for us to do it properly, we've really had to do some pushing around; that is, move the points.

MR. ALLAN:

All those points are not time measurements then.

MR. CHI:

That's correct.

MR. ALLAN:

That's hard to interpret.

MR. CHI:

I agree. I apologize.

DR. WINKLER:

Would it be possible to have your second, third and fourth slides again, quickly?

I think they're interesting and warrant further discussion because a question can be raised whether the procedures as used by the U.S. Coast Guard and the Naval Observatory in cooperation, are the best procedures.

If you look at the U.S. Naval Observatory over these 1,000 days or 900 days interval, there was one adjustment in this whole thing, one deliberate adjustment and it was on 1 May 1973. That's at the point when the slope reached zero.

The slope was left deliberately at zero in order to bring the time scale into agreement with the BIH which was not the case when the first adjustment was made at the transition point from old UTC to new UTC. At this point, as many of you remember, they made an adjustment of, what was it, some large number and the answer was I believe 760 microseconds and many more microseconds; 106,760—something like that.

A residual was left and our policy, in general, is to make as few deliberate changes of frequency as possible—to maintain as uniform an operation as possible.

In a system going through several levels of inter-comparison, such changes generates waves. If you intercompare two distant clocks which supposedly have to be kept in synchronization but which get their synchronization information through different branches, these waves can produce sizeable errors. Therefore, our fundamental policy is to make as few changes as possible.

We see our mission in producing as uniform a reference scale as humanly possible. That's the reason why we have some 24 clocks in our own system and use any information we can get, in addition, to check the performance. So in all of this period there has been only one adjustment, and now the question comes up what is going to happen next? We have two conflicting goals to follow. One is to stay as close to the BIH as is possible: the other one is not to make any deliberate frequency changes if we can avoid it. I foresee that we will go through a period of hesitation because of some of the recent events which I alluded to yesterday, have caused some uncertainty in our links across the Atlantic and between the various Loran-C chains, and some more portable clock visits will be necessary and we want to wait for the resumption of satellite timing and similar things like that. So there is going to be a period of uncertainty.

The next slide please. Well, there's nothing much to be said about it other than you see an obvious attempt by all of the National time and service systems, and laboratories to cluster around zero—to be as close to the BIH as is possible which is certainly a very convenient thing to be. Some don't think it is necessary to do much better than maybe 20 microseconds; 5 microseconds or 10 microseconds may be a practical limit to which one may allow an offset in any national reference clock.

Next slide, please. I must take this opportunity to commend the Coast Guard for doing an absolutely outstanding job in keeping these chains on frequency.

What you see here must be interpreted properly. You are looking at three years of data and these variations which you seem to see in reality are very long pieces of very uniform performance of each of these chains.

The question is, how often do you want to agree with the Coast Guard and us to make a deliberate frequency change which is announced in advance in Series 4 and how often do you want to introduce a step. Also one should add that an improvement in operation is done by equipping the master station with microphase steppers which allow a very accurate and reproduceable frequency change which may obviate the need for time steps altogether in the future.

But I wanted to say that what you've seen here, may in reality be the worst way of looking at an otherwise wonderful performance. Also, the West Coast Loran is quite another subject. Here considerable uncertainly existed for a while and it was our policy, as long as it was not an operational chain, to let it run freely and only make an adjustment after all the information was in. That's the reason for the relatively long delay before making the adjustment. But to sum it all up, I think that since the Loran chains operate for very extensive periods, this very reliable frequency, extremely reliable frequency, indeed better than almost every other monitoring station which we know. It is not necessary to introduce deliberate frequency changes, only at the frequency of once every three or four months, and they always are announced in advance.