Vellum Master

TELE-COMMUNICATIONS WORKING GROUP
(TCWG)

Inter-Range Instrumentation Group
(IRIG)

PLAN FOR GLOBAL TIMING SYNCHRONIZATION

Presented to IRIG Steering Committee

August 1961

TELE-COMMUNICATIONS WORKING GROUP
(TCWG)

Inter-Range Instrumentation Group
(IRIG)

PLAN FOR GLOBAL

TIMING SYNCHRONIZATION

Presented to IRIG Steering Committee

August 1961

TELE-COMMUNICATIONS WORKING GROUP
(TCWG)

Inter-Range Instrumentation Group
(IRIG)

PLAN FOR GLOBAL TIMING SYNCHRONIZATION

Presented to IRIG Steering Committee

August 1961

ABSTRACT

In response to a task assignment by the IRIG Steering Committee, the TCWG has investigated the need for precise time synchronization on a global basis. The TCWG determined that valid requirements exist for microsecond synchronization. TCWG then evaluated methods of achieving the required synchronization accuracy.

The TCWG recommends that the LORAN-C navigational system be utilized for precise timing applications and extended as required to provide global coverage during the next five year period. Integration of VLF techniques with LORAN-C techniques is also recommended. The VLF-LORAN-C approach will permit maximum utilization of existing transmitting chains.

Several problem areas are noted in the LORAN-C system where certain changes would enhance the system's usefulness for time determination and synchronization. It is recommended that these areas be throughly investigated.

TABLE OF CONTENTS

PLAN FOR GLOBAL TIMING SYNCHRONIZATION

ACKNOWLEDGMENTS

To accomplish the work herein described, three committees were established by TCWG. The following committees accomplished the necessary work and submitted their reports to the TCWG for approval:

Propagation Considerations	Dave Kasper, NOTS (Chairman) W. Wallingford, AFFTC L. W. Kruger, PMR
Requirements	R. L. Montgomery, WSMR (Chairman) L. E. Rogers, AMR L. W. Kruger, PMR
Techniques and Costs	L. Maurice Clelland, WSMR (Chairman)* D. Duckworth, NOTS Harry Lidkea, AMR

This report is based upon work of the above committees with guidance and consultation provided by other members of TCWG, especially by R. E. Rockstrom, TCWG Chairman. The TCWG particularly wishes to acknowledge the valuable assistance and information provided by Dr. William Marowitz of the U. S. Naval Observatory, Washington, D. C. and Mr. Gifford Hefley of the National Bureau of Standards, Boulder, Colorado.

*Also responsible for preparing this final report based upon work presented by the three committees and recommendations approved by the TCWG members.

PLAN FOR GLOBAL TIMING SYNCHRONIZATION

INTRODUCTION

At the IRIG Symposium in El Paso, Texas, November 1960, a task was assigned to the Telecommunications Working Group (TCWG) by the IRIG Steering Committee to prepare a plan for the next 3-5 years to accomplish the following:

1. Review and establish time synchronization requirements on a global basis.

2. Recommend method for time synchronization and correlation on a global basis.

To accomplish this work, the TCWG established three major AD HOC committees: Propagation Considerations; Synchronization Requirements; and, Techniques and Costs. The report of the Propagations Committee was submitted at the 16th meeting of TCWG in February 1961. That report appears as Appendix C in the Minutes of that meeting and as Appendix C to this report. Reports of the other two committees were presented at the 17th TCWG meeting at Boulder, Colorado in June 1961.

Since the functions of the three committees were directed toward the solution to one problem, i.e. establish a plan for precise time synchronization on a global basis, it was necessary for the chairmen to closely coordinate their activities. Further, the Techniques and Costs Committee could not finalize its work until the recommendations of the Requirements Committee were crystalized.

REQUIREMENTS

In order to obtain authoritative statements from National and Service Missile Ranges, from associated major Government agencies, and from Government-connected contractors as to the degree of time synchronization presently required and predicted, the TCWG prepared a questionnaire and cover letter which were distributed to selected group representatives. A copy of the questionnaire and cover letter, copies of the returned questionnaires, and a summary of the answers on the questionnaires are included as Appendix A to this report.

From the answers to this questionnaire received from the National and Service Missile Ranges, it has been determined that present synchronization requirements for these agencies are generally in the order of ± one millisecond. However, accuracy improvements predicted for missile and satellite tracking instrumentation systems in the next few years indicate that improvement by several orders of magnitude will be required for the instrumentation timing systems before the full capabilities of improved instrumentation tracking systems can be realized. Timing systems between ranges will have to be synchronized in 3 to 5 years to approximately ± 100 microseconds (one Range anticipates a requirement of ± 3 microseconds), and it appears that ± 3-10 microseconds is a realistic inter-range requirement for the foreseeable future.

From answers to the questionnaires received from agencies outside the missile ranges themselves and from contacts developed through IRIG associate organizations, it was determined that requirements presently exist, or will soon exist, for timing synchronization accuracies even more stringent than indicated by the missile ranges. A number of these requirements may be classified as of vital concern to the defense of this country. A summary of these contacts and requirement statements appears as Appendix B.

It has been deemed appropriate by the TCWG to consider not only inter-range requirements but also other agency requirements in order to recommend an IRIG timing synchronization system which would be compatible with or would form the nucleus of a practical world-wide system for National use.

The TCWG finds that valid requirements presently exist in a number of areas of endeavor for synchronization of widely separated clocks to accuracies more precise than those normally provided by presently available techniques and hardware. (Only HF radio, WWV and WWVH, and VLF radio, NBA and GBR are presently available for time synchronization use. More complex techniques such as the transportation of an Atomic standard are not within the realm of practicality for most users.) Precise synchronization requirement areas include the following:

a. Missile and satellite instrumentation systems.

b. Secure communications systems.

c. Scientific studies of propagation phenomena.

d. Evaluation and adjustment of precision oscillators.

e. Certain classified defense systems.

As the 3-5 year goal, the TCWG recommends the adoption of the LORAN-C method of achieving inter-range time synchronization. The establishment of inter-range synchronization by this method will undoubtedly be a giant step toward obtaining world-wide microsecond synchronization of timing. The benefits to the United States Government in obtaining this world-wide capability are tremendous. It would significantly enhance not only Department of Defense activities but also numerous R&D activities that may be directly related to advancing the state-of-the-art in future precise systems needed by DOD and other U. S. Government agencies.

TECHNIQUES

Over the past few years, two practical methods have been proposed to achieve fractional-millisecond time synchronization accuracies on a world-wide basis: namely, VLF and LORAN-C. The transporation of an Atomic standard to various sites to check and set the local clocks has also been considered; however, this method would be extremely costly, would require almost continuous scheduled "flying" of the standard to each user's sites, would require a special trip with the standard upon any failure which interrupted the local clock, and generally would not be readily available to agencies who were not serviced by such a transportable standard. Because of these serious limitations, the TCWG excluded this method and investigated the characteristics of the VLF and LORAN-C systems. Further, the techniques of using each of these systems were fully investigated.

During the February 1961 meeting of the TCWG, laboratory demonstrations of both methods were observed at the U. S. Naval Observatory, Washington, D. C. The VLF demonstrations were successful. However, the modified navigation receiver used in the LORAN-C demonstrations did not function properly, and the results were inconclusive. The chairman of the Techniques and Costs Committee visited NBS, Boulder, Colorado in March 1961 to observe the new LORAN-C timing receivers that were operating on ground wave from the East Coast LORAN-C chain. These demonstrations clearly indicated that microsecond synchronization could be achieved within ground wave coverage areas.

In order to obtain the characteristics of each system, all available technical reports and bulletins pertaining to time service and to VLF and LORAN-C transmission systems were reviewed. (See Appendix F.) Also, propagation characteristics were studied (see Appendix C).

Considerable work pertaining to a LORAN-C clock and synchronization between widely separated clocks has been accomplished by the National Bureau of Standards, Boulder, Colorado. NBS sponsored the development of the new LORAN-C timing receivers and a LORAN-C clock with microsecond read-out capability. Results of those developments and of the many NBS studies are available in the reports that NBS has issued. These reports were meticulously studied by the Techniques and Costs Committee in order to fully use results of previous work on timing synchronization. A summary of pertinent technical data on the VLF and LORAN-C systems follows:

a. Pulse rise time: LORAN-C is about 70 microseconds (7 cycles of 100 KC); VLF is approximately 15 milliseconds

b. **Signal dilution:** Within the area of ground wave coverage, the LORAN-C signal is sampled before the arrival of the first sky wave thereby eliminating error caused by ionospheric variations; VLF signals are contaminated by sky waves for all usable portions of the pulse.

c. **Cycle detection:** During a sampling interval, the zero axis crossing of a particular cycle of the LORAN-C carrier is determined to an accuracy of better than one microsecond; a particular cycle of VLF cannot be identified with sufficient accuracy.

d. **Diurnal or seasonal variations:** LORAN-C ground wave signal is not significantly affected (signal sampled before arrival of sky wave) but the sky wave signal would vary (about the same as VLF); VLF ground wave signal is affected because of sky wave contamination.

e. **Transmission delay:** (1) LORAN-C ground wave signal propagation delay is predictable within nominal limits of 0.1-1.0 microseconds to approximately 2000 miles; VLF ground wave signal delay is predictable but subject to sky wave dilution for usable portions.

(2) The ionospheric reflections are subject to substantial, but generally pedictable diurnal variations at sunrise and sunset. During stable periods, the sky wave signals can approximately be predicted to within 10 microseconds.

f. **Phase locking:** After the exact time has been set in the local generator, the local timing oscillator can be slaved to either the LORAN-C or VLF signals to provide extremely useful continuous synchronization.

The principal advantages and disadvantages of using the VLF and LORAN-C systems for timing synchronization are shown below.

VLF

Advantages	Disadvantages
1. Virtual world-wide timing coverage is provided by existing transmitters over at least some part of each day.	1. Slow rise time of transmitted pulse (approximately 15 milliseconds) makes determination of the pulse beginning difficult (500 microseconds, however, 100 microseconds max. accuracy may possibly be achieved but this has not been demonstrated).
2. Relatively inexpensive equipment is required at each receiving station ($2500-$4500).	2. Due to the slow pulse rise times, all usable portions of the transmitted pulse suffer from sky wave contamination.
3. Synchronizing signals occur at a 1 pps rate during periods when communications is not being handled.	3. At present, NBA transmissions are interrupted to handle communications.
4. The duty cycle of the transmitted pulse (30%) simplifies the task of phase measurements.	
5. Good and predictable phase stability exists in spite of sky wave contamination effects. (Diurnal shift on the order of 40-50 microseconds between Balboa and Washington.)	

LORAN-C

Advantages	Disadvantages
1. Faster pulse rise times allow the signal to be detected before sky wave contamination occurs for ground wave coverage to about 2000 miles.	1. Only limited ground wave timing coverage (approximately 2000 miles radius during daylight) provided by the existing East Coast Chain.
2. Faster pulse rise times in conjunction with sophisticated techniques makes it possible to determine a known point of the pulse to within 0.1 microsecond at best using existing techniques.	2. The large variety of repetition rates, and the signal codings employed result in costly timing receivers ($30,000 each which may be reduced with quantity procurement).
3. Absence of sky wave contamination results in extremely good phase stability (less than 0.1 microsecond in pure ground wave conditions).	3. The limited ground-wave range of each transmitter results in a large number of transmitter chains to make full use of the LORAN-C one-microsecond synchronization capabilities. (Approx. $500,000 plus building facilities per station).
4. Virtual world-wide timing coverage could be integrated to provide world-wide navigation coverage from the same uninterrupted transmissions (accuracies of ground wave coverage 1 microsecond and of sky wave coverage about 10 microseconds).	4. Since many of the repetition rates used in the LORAN-C system (e.g. 10.01001--pps) are not integral multiples of one pps, the operational problems of maintaining time synchronization are unduely complicated.

From the above it is evident that for synchronization accuracies in the neighborhood of 500 microseconds, VLF is adequate, and the expense of the LORAN-C system is not justified. Since world-wide synchronization accuracies below 50 microseconds are required, it would appear that a program for constructing LORAN-C transmitters and receivers must be embarked upon. Under these conditions a large number of "Specific" rates would be required for station identification, which would make the process of transmitting time information around the world-wide chain or obtaining time information from this chain extremely tedious. For example, the repetition rate of 10.01001---pps quoted previously means that one of the pulses of this repetition rate is co-incident with 1 pps "on time" only once in every thousand seconds. A special divider could be fabricated to provide these peculiar reptition rates. However, this divider could be compared with one pps "on time" only once in every thousand seconds. Although this divider could be very accurately synchronized to the received signal, synchronization between this divider and the main 1 pps divider could be checked only once in every 16-2/3 minutes without the use of specialized operating techniques. The hardship to station personnel in maintaining synchronism under these conditions would be enormous. Furthermore, reliability of the overall timing synchronization scheme due to the incorporation of this additional complex divider is reduced.

These difficulties could be surmounted if only those rates which are co-incident with 1 pps "on time", every second, or integral multiples of once per minute, be considered for transmission of time synchronization information. A simple divider chain operating under these conditions could then be automatically synchronized by one ppm "on time" from the existing time base generators. If only six "Basic" repetition rates are used for transmitting accurate timing information, only six chains could be used without confusion, unless additional phase coding schemes are used for station identification.

A minimum of five LORAN-C chains synchronized to Universal Time and appropriate monitor stations to provide "steering" must be situated at strategic locations (see Figure 1) around the equator: e.g., the U. S. East Coast; Ascension Island; Mauritius; Manus Island; and Hawaiian Island. Stations at those locations (approximately 5000 miles apart) are most likely to provide the best sky wave coverage, according to NBS findings. In this netword, two chains are already installed: the U. S. East Coast; and, the Hawaiian Islands. Unfortunately, the Hawaiian chain does not broadcast at a Basic rate. However, it is believed that this chain could be changed to a Basic rate, if required. To assure adequate coverage for some special applications, it may also be necessary to synchronize the existing Mediterranean and Aleutian LORAN-C chains to Universal Time.

In addition to the LORAN-C chains proposed above, two other single LORAN-C transmitting stations are required within the U. S., e.g. Boulder, Colorado-WSMR area and the U. S. West Coast. These two stations would not be part of a navigational chain and thus would only provide timing synchronization links to insure precise inter-range synchronization within the continental U. S.

With this network installed, timing stations located anywhere on the globe between the Tropic of Cancer and the Tropic of Capricorn would seldom be more than three thousand miles from the nearest synchronizing source. This would insure that time synchronization at any point in this area could be checked to within ten microseconds during at least some part of each day. This, however, does not guarantee that the timing stations will be in synchronism to within 10 microseconds of each other for the following reasons: If five parts in 10^{10} stability oscillators are used at each station, time drift throughout the day in the absence of a synchronization signal could be approximately $\pm$ 40 microseconds, provided that the initial oscillator setting was accurate to within one part in 10^{10}. An additional $\pm$ 9 microseconds per day error can be expected for each part in 10^{10} initial frequency offset. Thus, two timing stations, initially synchronized to within $\pm$ 10 microseconds of the synchronizing source (20 microseconds of each other) could conceivably be 100 microseconds out of synchronism by the time LORAN-C reception is again available one day later.

Because of the above problems using sky waves, it is desirable to utilize the LORAN-C signal to initially synchronize the system during periods of good reception and to maintain phase synchronism with VLF signals during periods of poor LORAN-C reception. Using this technique, time correlation between the timing station and the synchronizing source could be maintained to within 10 microseconds, provided of course that the phase lock between the VLF and LORAN-C transmitters is kept constant to within two or three microseconds (although there may be an offset of up to 200 microseconds between the NBA and LORAN-C transmitters, as long as this offset is maintained to within two or three microseconds continuously, the synchronization requirements will have been met). It is believed that the Naval Observatory has the facilities to maintain the required synchronism between the East Coast chain of LORAN-C transmitters and the VLF station in the Canal Zone (NBA).

In areas covered by LORAN-C ground wave, the LORAN-C timing receiver can be used to provide a phase-lock signal for continuous slaving of the local timing oscillator. Thus, either the VLF or LORAN-C receiver may be used for "slaving" in areas of LORAN-C ground wave coverage. However, a VLF receiver should be provided as a part of the synchronizing system because it could also be used to provide a standard for phase comparison and slaving of the local oscillator to carry the station through periods of poor LORAN-C reception (mainly in marginal sky wave areas). If the VLF receiver is used for this purpose, it could also identify the UT second for setting the local clock. If not, then a high frequency receiver would be required to provide the "coarse" time setting (WWV signals) because LORAN-C signals furnish only "fine" timing signals.

SYSTEM IMPLEMENTATION

In order to achieve inter-range and global timing synchronization using combined VLF and LORAN-C, it is necessary to identify items that must be accomplished in relation to the transmitting systems and to investigate ways of economically improving the system for timing synchronization.

The LORAN-C is basically a navigational system, and the VLF (NBA) station is basically a world-coverage communication station. Thus, both types have certain limitations for timing use. The required changes in equipment and procedures can be implemented without deteriorating the original intended use for each system. Additional LORAN-C chains can be used for navigation and timing synchronization.

Existing LORAN-C chains must be up-dated. The station crystal oscillator unit must be replaced with a more precise unit. The problem of repitition rates must be solved (this item was discussed with NBS Boulder who further discussed the subject with the U. S. Coast Guard and Sperry Corp. and it appears that a change in method of assigning repetition rates can be solved satisfactorily). The transmissions from the master station must be monitored by the "Steering" agency (see Appendix E) to provide correction information when the transmitting station oscillator drifts away from Universal Time beyond tolerance. Propagation delay times must be accurately computed for each major range synchronizing location and other areas around the world. In addition, a study of sky wave propagation effects should be initiated to increase system accuracy and reliability. This study should include measurement and analysis of signals in areas where sky waves must be used (see Appendix D).

New LORAN-C chains and appropriate monitor stations must be installed to obtain world-wide coverage. Also, two timing-only LORAN-C transmitting stations must be installed at appropriate locations within the U. S. to insure microsecond synchronization between the National and associate Missile Ranges and other test Ranges.

The "Steering" agency must monitor the VLF station to maintain a constant time-phase relationship between VLF transmissions and LORAN-C chains. This will allow the user to choose either VLF or LORAN-C signals for phase-locking his local oscillator, depending upon the accuracy and reliability of signals at his location.

The user will have a choice of two approaches in timing equipment configuration. His selection of approach will be influenced by his existing equipment configuration and by the specific requirements in his area.

First, the NBS developed LORAN-C clock (see Figure 2) with added timing generation circuitry could provide IRIG format timing generation and synchronization. The NBS LORAN-C clock without additional circuitry would provide only synchronization and microsecond readout of random event capability. The use of this clock would probably not be the most economical method of achieving microsecond synchronization, if the user already possesses an IRIG Standard Format generator. The NBS clock contains a "slaved" oscillator, divider circuitry, and displays of time information (microseconds, seconds, minutes, hours, and days) which may duplicate generator items. The LORAN-C timing receiver used with this clock was developed by Sperry Corp. under NBS contract. It is an excellent receiver but contains many complex circuits and controls that are not required by each user. Therefore, NBS was advised that TCWG is interested in simplification of the LORAN-C receiver design to reduce the production costs as an immediate goal. NBS contacted Sperry Corp. who is now considering the problem. Examples of simplifications are as follows: repackaging (spread out components); modular design, but not weight compressed; elimination of some items such as notch filter and guard alarm channel (most items eliminated can be offered as optional); oscillator will be furnished by user; change power input from 400 cycle to 50-60 cycle; use of packaged circuitry; use plug-in units for station selection; and, oscilloscope and antenna provided by user.

The second approach would be used with IRIG timing generators similar to those purchased by PMR. This method requires a LORAN-C timing receiver and slaved oscillator (either VLF or LF phase-lock). Also, special circuitry can easily be designed to provide microsecond readout capability of the timing generator, if required by the user.

Both of the above approaches are compatible because they use the same techniques in measuring and adjusting the local generator signal to synchronize with Universal Time. In either case, a VLF receiver would be required as noted previously under Techniques.

Since both approaches require the use of a LORAN-C receiver and since the proper functioning of this receiver will affect the precision of synchronization between widely separated clocks, a study must be conducted to determine standard measurement and calibration techniques to be followed by the user.

Another problem of implementation will be the availability of funds on a timely basis such that joint procurement action for LORAN-C timing receivers can be accomplished through TCWG and such that all proposed LORAN-C chains and monitor-steering stations are installed in an effective manner to achieve inter-range and global timing microsecond synchronization within the next 3-5 years.

COSTS

Since other DOD Agencies have cognizance over the VLF and LORAN-C transmitting and monitoring systems, the TCWG has made no attempt to summarize the detail costs involved for them.

It was not possible to obtain exact cost figures for user synchronization equipment discussed above because none of that equipment is in production. However, appropriate personnel of various groups were contacted in order to arrive at the "best" estimated costs.

First Approach:	a.	NBS LORAN-C clock	$20,000
		Existing LORAN-C timing receiver	30,000
		VLF receiver	4,000
		TOTAL	$54,000
	b.	NBS LORAN-C clock	$20,000
		Simplified LORAN-C timing receiver	10,000
		VLF receiver	4,000
		TOTAL	$34,000
	*c.	IRIG Format Generation circuitry for use with either "a" or "b" above (Single unit generator)	$15,000
Second Approach:	a.	Special circuitry	$ 5,000
		Existing LORAN-C timing receiver	30,000
		VLF receiver	4,000
		TOTAL	$39,000
	b.	Special circuitry	$ 5,000
		Simplified LORAN-C timing receiver	10,000
		VLF receiver	4,000
		TOTAL	$19,000

*Cost of IRIG Format generation circuitry is shown because a user who does not possess an IRIG generator may desire to combine the generation and synchronization equipment. (Total cost using "b" and "c" is $49,000 per single unit.)

The cost of the existing LORAN-C timing receiver is shown for use by Agencies requiring all functions. Discussion with a Sperry Corp. representative revealed that the cost of the LORAN-C timing receiver can almost certainly be reduced through redesign to simplify it (the approximate cost of $10,000 is based upon their estimate of a world market for these receivers).

Most of the Ranges are in the process of procuring IRIG Standard Format generators and thus would use equipment listed under item "b" of the second approach for each site requiring direct synchronization. The number of sites and amount of equipment required by each range will be tabulated later when TCWG prepares a joint procurement plan.

RECOMMENDATIONS

1. LORAN-C be adopted as the primary method of achieving microsecond synchronization.

2. VLF be used to augment LORAN-C in LORAN-C signal problem areas.

3. Additional LORAN-C transmitting and monitoring stations be established by DOD add other interested agencies to obtain ground wave coverage across the U. S. and reliable global sky wave coverage.

4. LORAN-C transmitting stations be equipped with oscillators stable to one part in 10^{10} per day or better (requires action by the U. S. Coast Guard).

5. Scheme of Specific rates now used in LORAN-C be reviewed for the purpose of simplifying time synchronization: e.g., if the specific repetition periods differed by increments of one millisecond instead of 100 microseconds, NBA or similar one-per-second pulses could be used in a straight forward manner to resolve the repetition period and set the local clock (requires joint effort by NBS, U.S. Coast Guard, and TCWG).

6. LORAN-C system be "Steered" by the U. S. Naval Observatory (see Appendix E, this is presently an assigned function).

7. The phase-lock relationship between the master LORAN-C and NBA (VLF) transmissions be maintained by the U. S. Naval Observatory to within ± 3 microseconds. This would not only increase the effective use of LORAN-C but also allows VLF only to be used as a "course" synchronization medium.

8. NBS be requested to assist in determining propagation constants between LORAN-C stations and specific locations within IRIG member ranges (requires site location data and funds by TCWG action).

9. NBS be requested to provide specifications for standarization of receiver calibration (requires funds by TCWG action).

10. DOD assist the U. S. Coast Guard in funding work by NBS to further investigate sky wave propagation of LORAN-C signals (see Appendix D).

11. NBS and TCWG work jointly with Sperry Corp. to determine the feasibility of simplifying the LORAN-C receiver for range timing applications without sacrificing performance.

12. TCWG member ranges insure that phase-locking techniques used in slaving the local oscillator shall not degrade the short term stability of the local oscillator by more than a factor of two.

13. TCWG formulate definite plans for joint procurement action. To be effective, joint action will require support at the Range Commander level.

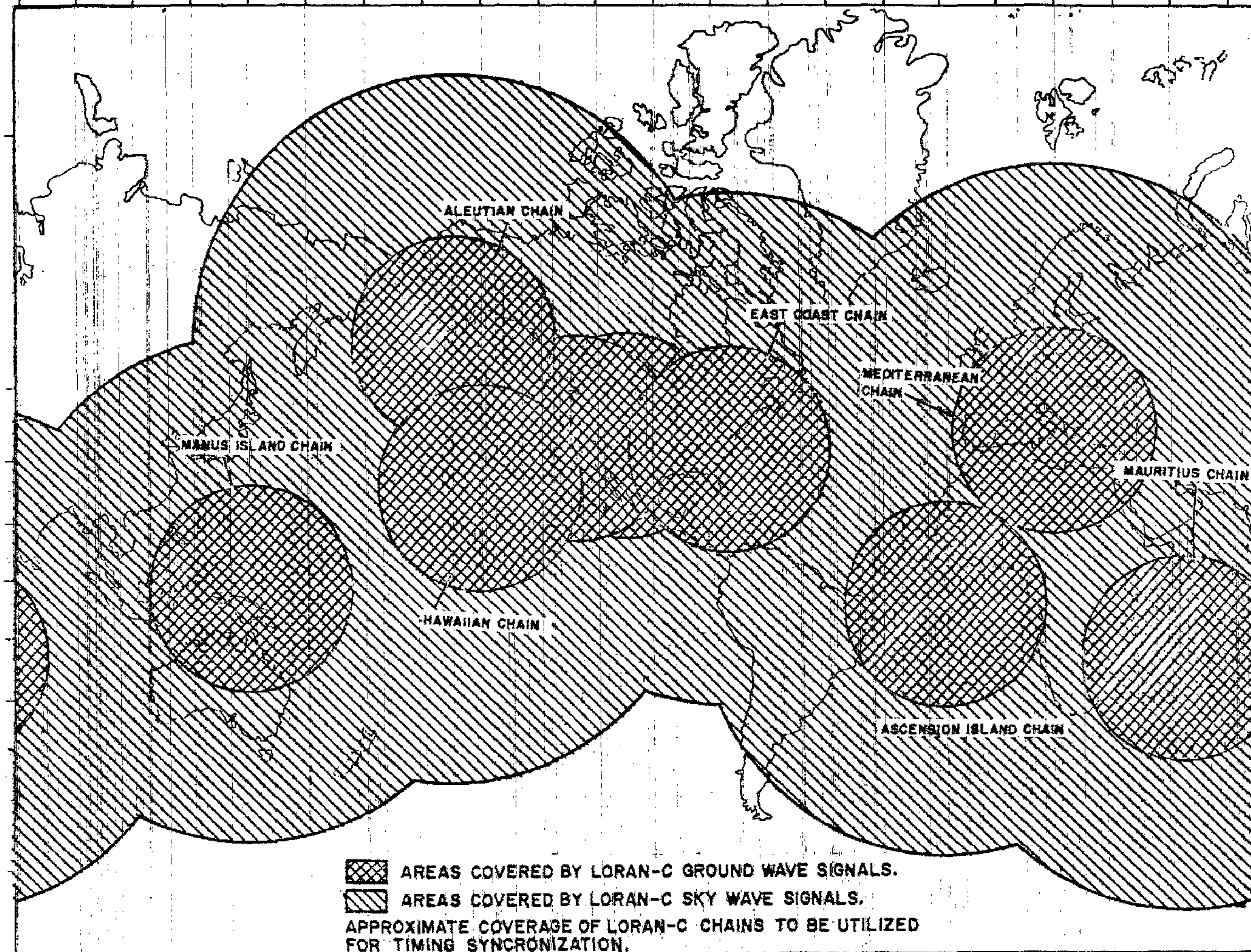
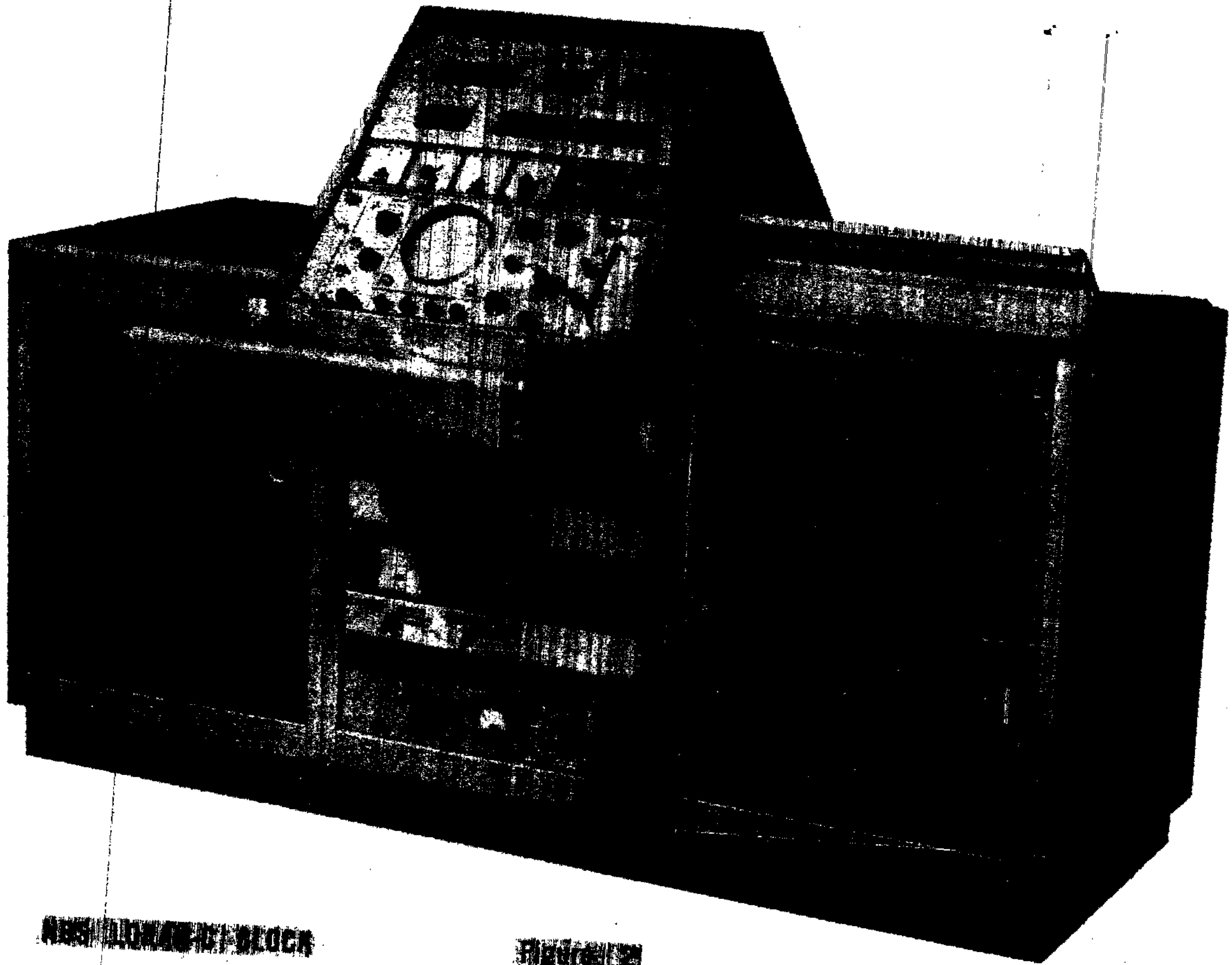


Figure 1 TIMING SYNCHRONI



NBS [illegible] CLOCK

Figure [illegible]

TIMING SYNCHRONIZATION REQUIREMENTS
OF TEST RANGES
(SUMMARY FROM QUESTIONNAIRES)

Agency	Present	3-5 Years	Future
WSMR			
IRM-RID	± 1 ms.	± 3 u sec.	± 1 u sec.
SMSA Radar	± 1 ms.	± 50 u sec.	± 1 u sec.
SMSA Freq. Div.	± 0.115 ms.	± 100 u sec.	± 50 u sec.
NOTS			
Test Dept.	± 1 ms.	± 100 u sec.	± 10 u sec.
PMR	± 1 ms.	± 100 u sec.	± 10 u sec.
AFGC			
FOVED	± 1 ms.	± 1 ms.	± 1 ms.
AMR	(Questionnaire not returned)		
AFFTC	(Questionnaire not returned)		
FAA			
Bureau of R & D	(Questionnaire returned but unable to answer question at present)		
Sandia Corp.			
Inst. Dev. Dept.	± 1 ms.	± 100 u sec.	± 100 u sec.
NASA			
JPL	± 1 ms.	± 100 u sec.	± 100 u sec.
Goddard Space Flight Center	± 25 ms.	± 5 ms.	± 2 ms.
AFCRL (Cambridge)			
Research Probe Inst. Br.	± 1 ms.	± 100 u sec.	± 100 u sec.
USAEPG			
(Ft. Huachuca)	Not required	± 100 u sec. (?)	Unknown
AFMDC			
Oribital Mechanics Div (MDWO)	± 5 ms.	± 3 ms.	________
Directorate of Adv. Technology (MDRTI)	± 1 ms.	± 100 u sec.	________

Names and addresses of the individual sources for the above information can be found on the reproduced copies of the returned questionnaires included as a part of this report.

19 January 1961

Dear Sir:

The Telecommunications Working Group of the Integrated Range Instrumentation Group has been assigned a number of tasks dealing with the accuracy requirements of range timing for instrumentation. Completion of these tasks should result in information which will be of considerable benefit to all range instrumentation and result in improved data accuracy.

It is requested that the enclosed letter and questionnaire be placed in the hands of proper authority within your agency to supply competent and reliable answers. Please note that the questionnaire should be returned to the undersigned by 10 February. Your cooperation will be greatly appreciated.

R. L. Montgomery
Associate TCWG - IRIG
Box 394
Holloman Air Force Base, N. M.

(Committee Chairman)

RLM/dp

16 January 1961

TO:

FROM: Committee to Review and Establish Time Synchronization Requirements on a Global Basis, Telecommunications Working Group of the Inter-Range Instrumentation Group.

1. The Steering Committee of the IRIG has assigned a series of tasks to the Telecommunications Working Group, one of which is concerned with the "Reviewing and establishing of time synchronization requirements on a global basis - at the present time and as anticipated three to five years in the future". A committee within the Telecommunications Working Group was set up to deal with this portion of the task assignment.

2. In order to communicate with other groups or agencies on a common language basis the committee has adopted the following definitions:

a. Time Synchronization - The state of taking place at the same instant of time

b. Simultaneity - Same as above

c. Time Correlation - The act or process of establishing a mutual or reciprocal relation to an instant of time. This relation is expressed as an interval of time.

d. Universal Time(UT-2) - Mean solar time corrected for observed polar motion and for extrapolated seasonal variations in speed of rotation of the earth. The second of mean solar time is 1/86,400 of a mean solar day.

3. After reviewing information available in connection with inter-range time synchronization requirements on the National and Service Missile Ranges the committee has determined the following:

a. The vast majority of inter-range and global time synchronization requirements indicate that a need exists for timing simultaneity, as presented to the user, to at least the following accuracies -

Present $\pm$ One Millisecond

3 - 5 years in future $\pm$ 100 Microseconds

b. Although more stringent requirements appear to exist, it is desirable to determine if these can be satisfied by post-flight or delayed correlation correction figures. It is also possible that timing simultaneity requirements can be relaxed at a timing generator site, in some cases, if accurately known figures can be supplied for the propagation delay between the timing generator site and the end instrumentation.

c. Present techniques and "hardware" known to be employed at missile ranges will not confidently yield ± one millisecond timing simultaneity to Universal Time (UT-2). Uncertainties of ± 2 1/2 milliseconds are considered realistic by the use of available methods.

4. To assist this committee in formulating the required course of action to satisfy the specified task, any exceptions to the stated accuracies in paragraph 3.a should be brought to the committee's attention through the media of the attached questionnaire. Information developed by this committee must be acted upon by other committees in establishing the methods and equipment to be employed, and the specifications for equipment must be prepared prior to the next fiscal year. The committee is scheduled to meet next on the 13th of February. It is, therefore, extremely important that the questionnaire reach the undersigned no later than 10 February. Your cooperation will be greatly appreciated.

R. L. Montgomery

R. L. Montgomery
Associate TCWG - IRIG
Box 394
Holloman Air Force Base, N. M.

(Committee Chairman)

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± ________ milliseconds	________ days
In 3 - 5 years	________	
Foreseeable future	________	

Type of instrumentation ________________________________

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± ________________

In 3 - 5 years ________________

Foreseeable future ________________

Type of instrumentation ________________________________

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? ________ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers ________________________________
Name (printed) Signature

Organization ________________________________

Mailing address ________________________________

____

____

TIMING SYNCHRONIZATION REQUIREMENTS
SUMMARY FROM QUESTIONNAIRES
(SIMULTANEITY TO UT-2)

IRIG Member Ranges

Agency	Present	3-5 Years	Future
WSMR			
IRM-RID	± 1 ms.	± 3 u sec.	± 1 u sec.
SMSA Radar	± 1 ms.	± 50 u sec.	± 1 u sec.
SMSA Freq. Div.	± 0.115 ms.	± 100 u sec.	± 50 u sec.
NOTS			
Test Dept.	± 1 ms.	± 100 u sec.	± 10 u sec.
PMR	± 1 ms.	± 100 u sec.	± 10 u sec.
AFGC			
FOVED	± 1 ms.	± 1 ms.	± 1 ms.
AMR ~~(Questionnaire not returned)~~	*± 1 ms.*	*± 100 u sec.*	*± 10 u sec.*
AFFTC ~~(Questionnaire not returned)~~	*± 1 ms.*	*± 100 u sec.*	*± 100 u sec.*
FAA			
Bureau of R & D	(Questionnaire returned but unable to answer question at present)		
Sandia Corp.			
Inst. Dev. Dept.	± 1 ms.	± 100 u sec.	± 100 u sec.
NASA			
JPL	± 1 ms.	± 100 u sec.	± 100 u sec.
Goddard Space Flight Center	~~± .25 ms.~~ *± 1 ms*	~~[illegible] ms.~~ *± 100 u sec.*	~~[illegible] ms.~~ *± 10 u sec.*
AFCRL (Cambridge)			
Research Probe Inst. Br.	± 1 ms.	± 100 u sec.	± 100 u sec.
USAERG			
(Ft. Huachuca)	Not required	± 100 u sec. (?)	Unknown
AFMDC			
Oribital Mechanics Div (MDWO)	± 5 ms.	± 3 ms.	
Directorate of Adv. Technology (MDRTI)	± 1 ms.	± 100 u sec.	________

Names and addresses of the individual sources for the above information can be found on the reproduced copies of the returned questionnaires included as a part of this report.

COPY

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± ______ milliseconds	______ days
In 3 - 5 years	______	
Foreseeable future	______	

Type of instrumentation ______

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1 ms.

In 3 - 5 years ± 100 u sec.

Foreseeable future ± 10 u sec.

Type of instrumentation ______

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? ______ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers RICHARD D. MOORE
Name (printed) Signature

Organization AFMTC

Mailing address CMDR. AFMTC
PATRICK AFB, FLA
(MTLS)

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± ________ milliseconds	________ days
In 3 - 5 years	________	
Foreseeable future	________	

Type of instrumentation ________________

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1 ms.

In 3 - 5 years ± 100 u sec.

Foreseeable future ± 100 u sec.

Type of instrumentation ________________

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? ________ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers ________ Roy E. Rockston

Name (printed) Signature

Organization ________________

Mailing address ________________

____

____

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	____ days
IN 1 - 2 YEARS	3 MICROSECONDS	
In 3 - 5 years	3 MICROSECONDS	
Foreseeable future	1 MICROSECONDS	

Type of instrumentation ARTRAC SYSTEM DATA, INTEGRATED TRAJECTORY SYSTEM

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present	± 1 MILLISECONDS
IN 1 - 2 YEARS	3 MICROSECONDS
In 3 - 5 years	3 MICROSECONDS
Foreseeable future	1 MICROSECOND

Type of instrumentation ARTRAC SYETEM DATA, INTEGRATED TRAJECTORY SYSTEM

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? ________ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers L. MAURICE CLELLAND — L. Maurice Clelland
Name (printed) — Signature

Organization Integrated Range Mission, Range Instrumentation Development

Mailing address ORDBS-IRM-RID

WHITE SANDS MISSILE RANGE,

NEW MEXICO

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	2 days
In 3 - 5 years	50 Microseconds	
Foreseeable future	1 Microsecond	

Type of instrumentation Radar

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1 millisecond

In 3 - 5 years 50 microseconds

Foreseeable future 1 microsecond

Type of instrumentation Radar

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? Yes (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers PERRY L. WHITE, Chief, Radar Lab Branch — Perry L. White
Name (printed) Signature

Organization Radar Division, U. S. Army Signal Missile Support Agency

Mailing address White Sands Missile Range, New Mexico

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 0.115 milliseconds	— days
In 3 - 5 years	0.1	
Foreseeable future	0.05	

Type of instrumentation Doppler Receiving Facility for Satellites

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± ______
In 3 - 5 years ______ } Same as above
Foreseeable future ______

Type of instrumentation ______

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? NO (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers H. G. Hungate HGHungate
Name (printed) Signature

Organization Freq. Division, SMSA, WSMR, NM.

Mailing address Member FCWG

IRIG

Army Signal Missile Support Agency

WSMR, N.M.

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	2 days
In 3 - 5 years	0.1 "	
Foreseeable future	0.01 "	

Type of instrumentation ASKANIA, T/M, TIM, MIDAS, etc.

2. What is the most stringent timing similianeity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1 ms. Assumes NODAC use

In 3 - 5 years 0.1 "

Foreseeable future 0.01 "

Type of instrumentation TM, MIDAS, Digitilized TIM, etc.

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? ________ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers W. E. VORE [signature]
Name (printed) Signature

Organization NOTS

Mailing address NOTS
Associate Hd, Test Dept (Code 3003)
China Lake, Calif

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± ________ milliseconds	________ days
In 3 - 5 years	________	
Foreseeable future	________	

Type of instrumentation ________

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1000 MS

In 3 - 5 years 100 MS

Foreseeable future 10 MS

Type of instrumentation OPTICAL

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? NO (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers GEORGE B. TIMKO (Name (printed)) George B. Timko (Signature)

Organization PACIFIC MISSILE RANGE

Mailing address POINT MUGU, CALIFORNIA

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	1 days
In 3 - 5 years	1 MS	
Foreseeable future	1 MS	

Type of instrumentation BALLISTIC CAMERAS

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1 MS

In 3 - 5 years 1 MS

Foreseeable future 1 MS

Type of instrumentation BALLISTIC CAMERAS

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? YES (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers H. H STRONG JR — H H Strong Jr
Name (printed) Signature

Organization APGC - PGVED

Mailing address N. H. STRONG JR
APGC - PGVED-23
EGLIN AFB FLA

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 0.1 milliseconds	14 days
In 3 - 5 years	[illegible]	
Foreseeable future	[illegible] capability [illegible] program	

Type of instrumentation [illegible] Radar, [illegible]

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± No comment at this time as the [illegible] is in process of contracting [illegible]

In 3 - 5 years [illegible]

Foreseeable future [illegible] Radar & [illegible]

Type of instrumentation

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? No (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers [illegible] Williams — R.R. Williams
Name (printed) — Signature

Organization Bureau of Research & Development, Federal Aviation Agency

Mailing address Atlantic City, N.J.

[illegible]

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	10 days
In 3 - 5 years	1/10	
Foreseeable future	1/10	

Type of instrumentation Seismological

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1

In 3 - 5 years 1/10

Foreseeable future 1/10

Type of instrumentation Seismological

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? Yes (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers G. E. Hansche
Name (printed) Signature

Organization Instrument Development Department - 7220

Mailing address Sandia Corporation, Attn: B. H. Kay - 7222
Sandia Base
Albuquerque, New Mexico

QUESTIONNAIRE

INTERRANGE TIMING SYNCHRONIZATION

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for postflight reduction, needed by instrumentation operated by your range or organization?

	Accuracy of Correlation (milliseconds)	Maximum Allowable Delay in Receiving Correlation Correction
Present:	± 5	7 days
In 3 to 5 years:	± 1	
Foreseeable future:	± 1	

Type of instrumentation: Deep Space Instrumentation Facility Telemetering

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization?

Present:	± 1 ms
In 3 to 5 years:	± 0.1 ms
Foreseeable future:	± 0.1 ms

Type of instrumentation: Deep Space Instrumentation Facility Tracking Data

3. If not provided with the accuracies specified above, will the data be degraded to the extent that the program will be jeopardized? No.
If answer is yes, you will be contacted for further details.

Authority for above answers: E Rechtin
E. Rechtin, Chief, Telecommunications Div.

Organization: Jet Propulsion Laboratory, California Institute of Technology

Mailing address: 4800 Oak Grove Drive
Pasadena 3, California

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 10 milliseconds	7 days
In 3 - 5 years	1	
Foreseeable future	0.3	

Type of instrumentation Satellite Tracking Stations (Minitrack)

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 25 1 milliseconds
In 3 - 5 years ± 5 100 μsec
Foreseeable future ± 2 10 μsec

AS MODIFIED BY C.H. LOONEY, JR. AT BOULDER TWG MEETING

Type of instrumentation Satellite Tracking Stations (Minitrack)

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? No, see covering letter (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers Dr. Harry J. Goett
Name (printed) Signature

Organization NASA - Goddard Space Flight Center

Mailing address Greenbelt, Maryland

Questionnaire

Inter-Range T[illegible] Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1.0 milliseconds	______ days
In 3 - 5 years	± 100 MS	
Foreseeable future	± 100 MS	

Type of instrumentation Stellar Cameras & Radar Range Instrumentation

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 1.0 millisecond

In 3 - 5 years ± 100 MS

Foreseeable future ± 100 MS

Type of instrumentation Stellar Cameras & Radar Range Instrumentation

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? Yes (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers Charles H. Reynolds
Name (printed) Signature C H Reynolds

Organization CHARLES H. [illegible]
CHIEF, RESEARCH PROBE INSTR. BRANCH
[illegible] LABORATORY

Mailing address
HEADQUARTERS
[illegible] CAMBRIDGE RESEARCH LABORATORIES
[illegible]

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for past flight reduction, needed by instrumentation operated by your range or organization:

Accuracy of Correlation figure	Maximum allowable delay in receiving correlation correction figure
Present + Correlation to UT-2 - not required milliseconds	N/A days

In 3 - 5 years May be in accordance with your para 3a

Foreseeable future Unknown

Type of instrumentation Radar, Telemetry and Optics

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present +
-

In 3 - 5 years See paragraph 1 above

Foreseeable future

Type of instrumentation

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? No (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers FRANK J. LEW
Name (printed) Signature

Organization Electromagnetic Environmental Test Division, CDev

Mailing Address Director of Combat Developments
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

Questionnaire

Inter-Range Timing Synchronization

1. What is the most stringent timing correlation requirement to Universal Time (UT-2), for post flight reduction, needed by instrumentation operated by your range or organization:

	Accuracy of correlation figure	Maximum allowable delay in receiving correlation correction figure
Present	± 1 milliseconds	* N/A days
In 3 - 5 years	1/2 MS	
Foreseeable future		

Type of instrumentation Satellite Observation

2. What is the most stringent timing simultaneity requirement to Universal Time (UT-2), for real time, quick look, or immediate reduction, needed by instrumentation operated by your range or organization:

Present ± 5 milliseconds

In 3 - 5 years ± 3

Foreseeable future

Type of instrumentation Satellite observation

3. If not provided with the accuracies specified above will the data be degraded to the extent that the program will be jeopardized? _____ (yes or no). If answer is yes, you will be contacted for further details.

Authority for above answers TAFT NICHOLSON — Taft Nicholson
Name (printed) — Signature

Organization FACET EYE PROJECT (Mr W. E. Wecht Proj. Engr)

Mailing address Commander, AFMDC
Orbital Mechanics Div. MDWO
HAFB New Mexico

* Note: Project has own Xtal Clock

A-2

TIMING SYNCHRONIZATION REQUIREMENTS OF OTHER AGENCIES

Agency	Present	3-5 Years	Future
(1) NASA	± 2 ms.	± 100 u sec. (2 years)	± 10 u sec.

(Source for above: Letter dated 8 Feb. 61 from John T. Mengel, Assn't Director, Tracking and Data Systems Directorate, Goddard Space Flight Center, Greenbelt, MD., to Dr. William Markowitz, Naval Observatory)

Agency	Present	3-5 Years	Future
(2) GWG (IRIG)	± 1 ms.		

(Source from above: Letter dated 6 Feb. 61 from H. Erickson, Chairman GWG, to R. L. Montgomery. Letter is reproduced as a part of this report).

(3) Sylvania — Sylvania Electric Products, Inc. has a requirement for 10 u sec. timing "all over the U.S." Contact is Mr. Budwaite (address not determined).

(4) General Electric, Syracuse, N. Y. has a requirement for 1 u sec. timing synchronization within a 1000 mile radius of Cape Canaveral in connection with the MISTRAN system. Contact is Mr. Richard Steele.

(5) Lincoln Labs (MIT) has indicated that a number of research projects could use one microsecond timing synchronization but cannot afford to support, dollar-wise, for its implementation. Contacts are:

- A. W. Bishop, Radar applications
- Jerry Hyde, Special Radar link between Trinidad and Boston
- Steve Dodd, MISTRAN
- Paul Siberling, Special Radar Link and other programs
- Walter Morrow, Orbital Scatter
- Melvin Stone, Supervisor of several programs

(6) SAC, USAF presently requires one microsecond timing on special projects.

(Source for Items (3) through (6): Mr. Gifford Hefley, Chief Navigations Systems Section, Radio Systems Division, Central Radio Propagation Laboratory of National Bureau of Standards).

(7) AFCCDD (Cambridge), has a contractor that requires timing synchronization to better than "one part" in 10^9.

(Source: p. 11 of Minutes of 16th Meeting of TCWG, quoted from Mr. Daugherty of NBS).

Agency	Present	3-5 Years	Future
(8) Smithsonian Institute will have a requirement for 100 u sec timing synchronization "all over the world" in about one year for use by tracking cameras. Contact is Mr. C. Hagge of Smithsonian Institute, Satellite Tracking Program.			

PROPAGATION CONSIDERATIONS

Task project III, section b, of the overall TCWG assignment as outlined by the TCWG Chairman's letter of 18 November 1960 was detailed to cover the following areas: "(a) Investigate delay and their predictability comparing between VLF and LF; (b) Compare CW approach with pulse approach. Investigate phase distortion due to mixing of ground and sky-wave, and the ability to identify a precise point in time by each system; (c) Investigate the problem of propagation delay determination in the case of a moving vehicle (ship, etc.) without knowledge of position to extreme accuracy."

Two meetings were held on the above subjects: One at AFFTC in December of 1960 attended by Capt. John Conley, AFFTC; Wally Wallingford, AFFTC; and Dave Kasper, NOTS. The second meeting took place at NOTS with G. Hefley, NBS; Lawrence Krugger, PMR; Capt. J. T. Conley, AFFTC, and Dave Kasper, NOTS in attendance. Mr. Gifford Hefley is an Associate Member, TCWG, and Capt. J. T. Conley is a member of EPWG.

The following commentary is representative of the general views derived from the two informal meetings and also excerpts from current literature in this general area. The bibliography is not a complete list of available literature, but contains a few of the papers I have had an opportunity to read or scan (not study) in the short time provided. In many cases, further references will be found in those cited, i.e. "H. POEVERLEIN, Low and Very Low Frequency Propagation, AFTRC-TR-60-106, January 1960", a review dealing with observational results and theoretical studies in the field of low and very low frequency propagation and contains 128 references.

In general, the time correlation accuracies desired will predicate the degree of consideration that must be given the propagation aspect.

A. "Investigate propagation delays and their predictability comparing between VLF and LF."

Since the early part of the last decade interest in both VLF (3KC to 30 KC) and LF (30KC to 300KC) bands has steadily increased, due principally to the need for long-range navigation, data, and communication systems. The remarkable stability of VLF and LF propagation makes possible also a world-wide standard of time more accurate than now provided by time signals in the High Frequency Band. The basic methods of most systems providing timing, navigation, and position-fixing all involve a measurement of the time required for radio energy to propagate over the surface of the earth. The accuracy of such a measurement depends upon the variability of the propagation medium.

The lower frequencies are characterized by high reliability and regularity of reception. The ground wave is predominant up to relatively great distances and the wave reflected in the ionosphere is less variable with time of day, season and ionospheric disturbances than it is at higher frequencies. In general, these variations decrease with decreasing frequency with the most constant conditions found at the frequencies below 30 KCs. CW phase stabilities reported in the 10-20 KCs range for an all-daylight or all-night path are of the order of an average standard deviation of from 4 to 5 microseconds with peaks sometimes reaching 50 microseconds. The large variations can be attributed to phase interference between the various propagation modes. These propagation accuracies of the VLF CW signals can be visualized if we consider the boundaries of the earth and the ionosphere forming a waveguide and these signals progating via the dominant mode. Sunrise or sunset effects introduce a discontinuity in the upper surface of the waveguide (changes between day and night heights are from about 70 to 90 Km, respectively) which is continuous during the interval of time necessary for the sun to illuminate the entire ionosphere path under consideration. For example, the hours of an all daylight path between Washington, D. C. and Boulder, Colorado (2370Km) would be 12.8 hours in June and 7.2 hours in December; while an all daylight path between Moscow, U.S.S.R. and Boulder, Colorado (8,880 Km) is 6.3 hours in June and 1.7 hours in December. The hours of an all night path would be the reverse for the months mentioned. The constancy and regularity of phase also extends up into the LF region for C-W ground wave signals but over a lesser range, since attenuation rates increase with frequency.

The carrier to noise ratio available at the receiving location is an important factor and greatly effects the time required to obtain precision frequency comparisons, especially at long distances. Thermal and atmospheric noises have their greatest effect in the VLF and LF bands. Average noise levels decrease with increasing frequency, owing in part to the radiated spectrum and partly because of propagation attenuation. Thermal (manmade) noise may arise from any number of sources, such as power lines, industrial machines, diathermy machines, ignition systems, etc. Thus its characteristics vary over wide limits and it is relatively unaffected by diurnal or seasonal changes in the ionosphere. This rms noise level will be constant for a given location and its effects on frequency comparison accuracy can be readily calculated. Thermal noise measurements in decibels above one microvolt per meter in a one kilocycle bandwidth in the Ottawa-Seattle area ranged from approximately 68db at 10 Kcs (being about 53 db at 20 Kcs) to 33db at 100 Kcs.

Atmospheric noises (thunderstorms, sunspot activity), are more erratic in character. Consisting of short pulses with random recurrence, superimposed upon a background of random noise, they have a very different statistical nature in a wide bandwidth. When carrier phase or frequency stability is being considered, the narrow bands employed, 0.1 cps or less, will make the atmospheric noise statistics the same as thermal noise. Thus it is possible to calculate its effects on frequency comparison accuracy.

The actual C/N 1KC required will undoubtedly vary with the characteristics of the receiving equipment and the amount of effort spent in attempting to separate the desired energy from the undesired noise energy. The greatest concern to time signal accuracy is the variability of noise levels which generally increase with frequency.

In the VLF region both theory and experiment show that greater observing times are required for a given degree of frequency comparison than is true in the LF region. However, when long-range ground wave paths are considered, the low attenuation rates obtained in the VLF band make emissions in this frequency region useful for very long-range coverage. The shape of an attenuation-vs-frequency curve (db/1000m) has a minimum in the vicinity of 17 to 19 Kcs. Attenuation varies also with direction, East to West (magnetic) attenuation rates, may be as much as one or two db/1000m greater than West to East attenuation rates. The magnetic attenuation effect is expected to be more pronounced at night, greater at the lower end of the VLF range (10 to 14 Kcs), and relatively small in the vicinity of 20 Kcs and higher.

B. "Compare CW approach with pulse approach. Investigate phase distortion due to mixing of ground and sky wave, and the ability to identify a precise point in time by each system".

A CW signal received at a distance measured along the earth's surface from the transmitter consists of a contribution due to the ground-wave and contributions due to sky-wave components. The total signal amplitude will descible some of quasi-cyclic variation as the phase of each sky-wave vector varies relative to each other and relative to the somewhat constant phase of the ground-wave. The variation of amplitude as a function of time depends upon the reflection heights and reflection coefficients of the sky-wave, and upon the amplitude and phase of the ground-wave. The field strength of the ground-wave contribution at the receiver is a function of frequency, polarization, distance, earth curvature and the effective conductivity and dielectric constant of the intervening terrain. Theoretical studies by many have produced solutions for calculations of the ground-wave field intensities for propagation over a homogeneous and smooth curved earth but agreement seems to be lacking concerning the extent of tropospheric refraction effects at low frequencies. One article mentioned an empirical method to take in account the effect of a mixed path on the ground-wave field intensity that could also be extended to estimate the resultant phase of the ground-wave propagated over an inhomogeneous smooth earth.

The effective amplitude of the sky-wave modes at the receiver are considerably more complex. They are dependent upon related characteristics of the transmitting and receiving antennas, reflection coefficients of the ionosphere and earth, and the path length of the sky-wave. A C-W system must, of necessity, operate on the composite signal composed of the ground-wave and all the sky-wave modes. In order to identify a precise point in time, in a CW system, the ground-wave to sky-wave ratio must be fairly large to permit reliable identification of cycles. This is true only over relatively short ranges with respect to the signal coverage.

A pulse system, however, provides a means of identifying the various transmission modes and correspondingly a point in time. (Spherics, pulses usually produced by lightening discharge and propagated between the earth and ionosphere, have been used for some time in propagation studies). Thus the various predominant modes can be resolved and their phase measured independently. Usually the ground-wave mode is selected since its variation in transmission time is considerably less than the sky-wave modes. The phase delay of a signal traversing a path of mixed conductivities can generally be predicted to within microseconds or better, and ground-wave phase will be stable to within a few hundreds of a microsecond. When homogeneous paths of known conductivity are being considered, i.g. sea water, the phase delay can be predicted to better than 0.1 microsecond with about the same value for repeatability.

The propagating medium, at the low frequencies, does not impose any unusual restrictions on the modulating system or on determining the accuracy of reception. The transmitting antenna system seems to be the major limiting factor. The amount of power radiated by the transmitter and the shape of the radiated signal are functions of the radiation efficiency of the antenna. Practical antennas used at low frequencies are physically short compared with the operating wave length (approximately 10 miles at 10 Kcs), they also have a low radiation resistance and relatively high capacitive reactance. Small fluctuations in the antenna system insulator leakage resistance produced by wetting by fog, rain or sleet may cause variations in the base impedance of the antenna which produces a detuning effect. This is of particular importance in the case of pulses, because detuning of the antenna will result in signal distortion. This effect is usually compensated by providing a facility at the transmitter for remote tuning of the antenna inductance. The degree of attention paid to this particular perimeter will determine the shape and rise time of the transmitted pulse and the over-all system real time synchronization. As frequency decreases, the effects become more critical and will probably be the limiting factor on time pulse determination accuracy using VLF.

The phase stability and longer range capabilities of VLF have prompted investigation for methods to overcome these bandwidth restrictions. Synchronous antenna tuning with FSK, separate dual frequency transmissions (1 Kcs spacing), and alternate frequency transmissions (10 cps spacing) are recent examples. Over-all real time system accuracy in the order of 500 microseconds to one millisecond are being realized with recent developments in time synchronization techniques. Concurrent developments in VLF automatic data systems using MSK (minimum frequency shift keying, binary communication system) are anticipating keying speeds up to 240 wpm (approximately 90 cps). Possible accuracies, using VLF, of 100 microseconds or better might be achieved with future development but probable eventual accuracy will not be much less than 50 microseconds.

In the LF band the antenna bandwidth limitations are reduced permitting faster rise times and thus resulting in greater system accuracies. Also available frequency spectrum makes large bandwidths more practical. It is in this frequency range where long-range time synchronization accuracies of a microsecond or better have been realized due to recent modification to a navigational system.

Phase measurement of the sky-wave modes can be made at distances beyond ground-wave range but will be less reliable and will not provide the high accuracy obtained with the ground-wave. In general, a pulse system can use the first available time mode, which is resolved from the successive time modes, and therefore measurements are only effected by the phase variations of a particular mode. The range of 100 Kcs pulse sky-waves have been checked out to 3000 nautical miles with phase stability within a microsecond (excluding sunset and sunrise). The sunset and sunrise periods of instability are approximately half an hour for each ionospheric reflection point involved.

As mentioned before, when frequency decreases from LF to the VLF time pulses will be increasingly shaped and delayed by the time constants of the high-Q antennas typical of both VLF and low LF installations. In the VLF band it is not possible to transmit sufficiently narrow pulses to allow positive separation of the various propagation modes. The reason for this is that physically realizable antennas have extremely high Q resulting in antenna bandwidths of less than 100 cps. The sky-wave delay decreases at the lower frequencies which would require a greater bandwidth for resolution of the modes in the received composite wave.

The advent of operational pulse systems in the VLF and LF bands, with the corresponding development of new measuring techniques and instrumentation is leading to a better understanding of the mechanism of propagation within these frequencies. The propagation data being collected is of great value for comparison with the existing theories of propagation.

C. "Investigate the problem of propagation delay determination in the case of a moving vehicle (ship, etc.) without knowledge of position to extreme accuracy".

When using navigation systems where the basic principals involve a measurement of the time required for radio energy to propagate over the surface of the earth, position accuracy is directly related to propagation delay determination. If relative position accuracy is within 100 ft., then the maximum time accuracy will be approximately 0.1 microsecond, 1000 ft - 1 microsecond, 10,000 ft - 10 microsecond and so on. If navigation systems employing other techniques are utilized, i.g. Transit, it seems that this relationship will not be as close.

SUMMARY

A. A VLF C-W signal is more stable than an LF C-W signal.

B. Pulse methods provide greater accuracy at longer distances in establishing a time or phase reference at the receiving location.

C. Position accuracy is directly related to time or phase determination accuracy.

/s/ DAVE KASPER, Chairman,
Propagation Committee

UNITED STATES COAST GUARD

ADDRESS REPLY TO:
COMMANDANT
U.S. COAST GUARD
HEADQUARTERS
WASHINGTON 25, D.C.

EEE-4
J15-2/12-23

31 MAY 1961

National Bureau of Standards
Boulder Laboratories
Boulder, Colorado

Gentlemen:

Reference is made to the early correspondence wherein the National Bureau of Standards expressed interest in performing a study of the characteristics of sky wave propagation at 100 KC. The Coast Guard may be able to support a limited study program of this nature in the near future. In particular, the Coast Guard interest lies in the exploitation of skywave propagation of Loran-C for navigation. Additionaly, of course, this mode may also be of interest for timing.

The main aim of such a study would be the determination of the service area corrections to be applied to the presently computed ground wave time differences for the first hop sky wave signal between about 1200 and 3000 miles from the source.

Because the inherent accuracy of the Loran-C system stems from the phase measurement while ambiguity of phase is resolved by envelope measurement, the program would include inquiry into the sky wave characteristics of both envelope and phase. It would be expected that the effects of the earth's magnetic field would be included as well as any variations due to changes in the characteristics of the ionosphere as a function of latitude.

Since the program must be limited by economic considerations, the facilities to be employed would be those presently in existence. In this connection, the present five Loran-C systems can be made available to collect data. A U. S. Coast Guard electronic aircraft configured for Loran-C reception can be made available from time to time. Additionally, the Coast Guard contemplates the establishment of a sky wave monitoring station on the Pacific Coast - probably on the coast of Washington.

Within these limitations, the program for sky wave investigation in which we are interested is summarized as follows:

Purpose: To create a set of tables or charts which contain the sky wave corrections to be applied to the observed Loran-C time differences when the measurement is made on (a) the first hop sky wave of one signal and the ground wave of the other and, or (b) the first hop sky wave of both signals as appropriate to each service area.

Scope of Study:

Through acquisition of data from existing systems and study of the literature, to establish a mathematical model of the earth-atmosphere-ionosphere, including the magnetic field of the earth, from which the first hop sky wave of the envelope and phase characteristics of 100 KC Loran-C pulse may be approximated. Because the envelope information desired will be in the form of a correction to the ground wave envelope, the literature study will include an extension of the study of the low frequency ground wave to determine "the secondary group factor" for various conductivities of the surface of the earth. This group factor is to be analagous to the secondary phase factor contained in NBS 573.

Equipment and Facilities: Utilize present equipment in existence. The facilities and personnel of 5 Loran-C systems can be made available on a limited basis to acquire data. A Coast Guard aircraft can be made available for limited periods for area probes. Other facilities for study of ionospheric height and density, magnetic qualities of the earth's field, and atmospheric density are not available within the Coast Guard. In this connection, it is believed that National Bureau of Standards is aware of efforts by other government agencies which can provide much information in this region. It is not anticipated that new equipment will be developed solely for this study.

EEE-4

COMDT (EEE) ltr J16-2/12-23 to National Bureau of Standards.

__Funding:__ Because of the interest in the characteristics of LF sky wave propagation by agencies other than the Coast Guard, it may be that others would be interested in supporting a more extended program than is proposed here. If the Coast Guard is the sole support for this program, the purpose stated above will be the primary purpose of this effort.

It is suggested that a meeting of NBS, Hydrographic Office and USCG representatives be held in the near future to solidify this program. At this meeting the Hydrographic Office will present its correction factor requirements and the USCG will outline a program for sky wave data collection for NBS comment. If the National Bureau of Standards is interested in active participation in this program it is requested that the extent of participation and funding requirements be presented at this meeting.

Very truly yours,

E. H. Thiele

E. H. THIELE
Rear Admiral, U.S. Coast Guard
Engineer-in-Chief

OB 09B62
2400
Ser 1750

(b). The control of the basic oscillator at Cape Hatteras will be the same as at Carolina Beach.

(c). The Cape Hatteras equipment will permit precise control of the phase of the time pulses. The Naval Observatory will provide instructions for control of phase. Normally, it will not be necessary to instruct that a phase change be made unless the oscillator or dividers at the transmitting station have stopped.

4. Basic Oscillator.

(a). The stability of the time intervals transmitted by LORAN-C is controlled by a basic oscillator. At Carolina Beach a 5 Mc/s quartz-crystal oscillator of high precision is now used. A 2.5 Mc/s quartz-crystal oscillator of increased precision can be installed at Cape Hatteras.

(b). As the state of the art permits, atomic oscillators can be introduced for stabilization control. It is expected that gas cells can be introduced first. This should permit a stability of about 1 part in 10^{11}, the present goal. If the hydrogen maser meets theoretical expectations, it would permit a stability several orders higher.

5. LORAN-C Chains.

The Naval Observatory will control the frequency and phase of the East Coast master LORAN-C Station. When it becomes feasible for other LORAN-C chains to synchronize with the East Coast chain, either directly or indirectly, a coordinated system of timing will thus be provided.

B. L. GURNETTE

Copy to:
ODDR and E
CNO, OP-94
Director, ONR
Director, NRL (Code 5424)
Director, NBS, Washington
Director, NBS, Boulder Laboratories
BUWEPS
BUSHIPS
Patrick AFB, AMR
White Sands MR
PMR

BIBLIOGRAPHY

1. - H. POEVERLEIN, "Low and Very Low Frequency Propagation", AFCRC-TR-60-106, January 1960.

2. - A. D. WATT, R. W. PLUSH, W. W. BROWN, and A. H. MORGAN, "World-Wide Standard Frequency and Time Signal Broadcasting", NBS Report 6091, March 8, 1960.

3. - R. R. STONE, Jr., W. MARKOWITZ, and R. G. HALL, "Time and Frequency Synchronization of Navy VLF Transmissions", IRE Transactions on Instrumentation, Vol I-9, No. 2, pp 155-161, Sept. 1960.

4. - R. H. DOHERTY, G. HEFLEY, and R. F. LINFIELD, "Comparison of 100 Kc Pulse and VLF C-W Navigation and Timing Systems", Working Paper for Administrative Radio Conference (ITU) Geneva, Switzerland, 1959.

5. - A. D. WATT and R. W. PLUSH, "Power Requirements and Choise of an Optimum Frequency for a World-Wide Standard-Frequency Broadcasting Station", J. Res NBS-D. Radio Propagation Vol. 63D, No. 1, July-Aug. 1959, pp 35-44.

6. - J. R. JOHLER and L. C. WALTERS, "Transmission of a Ground-Wave Pulse Around a Finitely Conducting Spherical Earth", NBS Report 5566, April 17, 1958.

7. - J. R. JOHLER and LILLIE C. WALTERS, "On the Theory of Reflection of Low and Very Low Radio Frequency Waves from the Ionosphere", J. Res NBS-D Radio Propagation Vol. 64D, No. 3, May-June 1960, pp 269-285.

8. - W. Q. CRICHLOW, D. F. SMITH, R. N. MORTON, and W. R CORLISS, "World-Wide Radio Noise Levels Expected in the Frequency Band from 10Kcs to 100 Mcs", NBS Circular 557, August 1955.

9. - W. MARKOWITZ, "Accuracies in Time", Paper, presented at Second, Air Force Cambridge Research Center, Military Geodesy Seminar, Orlando AFB, 12-14 Jan. 1960.

10. - J. S. BELROSE, W. L. HATTON, C. A. McKERROW and R. S. THAIN, "The Engineering of Communication Systems for Low Radio Frequencies" P of IRE, Vol 47 No. 5, May 1959, pp 661-680.

11. - C. J. CASSELMAN, D. P. HERITAGE and M. L. TIBBALS, "VLF Propagation Measurements for the Radux-Omega Navigation System", P-of IRE, Vol 47 No. 5, May 1959, pp 829-839.

12. - WAIT, MURPHY, "Further Studies of the Influence of a Ridge on the L-F Ground-Wave", J. of Res NBS, Vol 61 No. 1, July 1958, Res Paper 2884.

13. - J. R. JOHLER and L. C. WALTERS, "Propagation of a Ground-Wave Pulse Around a Finitely Conducting Spherical Earth from a Damped Sinusoidal Source Current", IRE Tran on Antennas and Propagation, Vol AP-7, No. 1, Jan., 1959.

14. - H. G. WOLFF, "High-Speed Frequency-Shift Keying of LF and VLF Radio Circuits", IRE Tran on Comm Systems, Vol CS-5, No. 3, Dec. 1957, pp 29-42.

15. - J. R. JOHLER, "Magneto-Ionic Propagation Phenomena in Low and Very-Low Radio Frequency Waves Reflected by the Ionosphere", NBS Memorandum Report PM-85-33.

16. - R. H. DOHERTY, "Pulse Sky Wave Phenomena Observed at 100 Kc", NBS Report 6CB103 Feb 6, 1957.

17. - R. L. FRANK, "Multiple Pulse and Phase Code Modulation in the Loran-C System", IRE Trans on Aer and Nav Elec, Vol. ANE-7, No. 2, June 1960, pp 55-61.

18. - J. WAIT, "Transmission Loss Curves for Propagation at Very Low Radio Frequencies", IRE Trans on Comm. Systems, Vol. CS-6, No. 2, Dec. 1958, pp-58-61.

19. - J. R. JOHLER, "On LF Ionospheric Phenomena in Radio Navigation Systems", NBS Report 6722, Oct. 17,1960.

20. - R. F. LINFIELD, R. H. DOHERTY, and G. HEFLEY, "Evaluation of the Propagation Aspects of the Cytac System", NBS Report 4CB101, March 18, 1957.

21. - J. R. JOHLER, W. J. KELLAR, and L. C. WALTERS, "Phase of the Low Radio-Frequency Ground Wave", NBS Circular No. 573, June 1956.

22. - A. H. MORGAN, "Precise Time Synchronization of Widely Separated Clocks", NBS Tech Note No. 22, July 1959.

23. - J. R. WAIT, "Diurnal Change of Ionospheric Heights Deduced from Phase Velocity Measurements at VLF", Proc. of IRE, Vol. 47 No. 5, May 1959, pp 998.

24. - H. F. HASTINGS, "Precision Frequency Control and Millisecond Timing", NRL Progress, Aug.1960, pp 16-22.

25. - W. MARKOWITZ, "Timing Inter-Connection of Missile Ranges", Paper US Naval Observatory, 1 Nov. 1960.

26. - R. H. DOHERTY, G. HEFLEY and R. F. LINFIELD, "Timing Potentials of Loran C", NBS Report 6720, Oct. 17, 1960.

27. - G. HEFLEY, R. F. LINFIELD and R. H. DOHERTY, "Timing and Space Navigation with an Existing Ground Based System", NBS Report 6721, Oct. 17, 1960.

28. - R. H. DOHERTY, T. L. DAVIS and E. L. BERGER, "LORAN-C Timing Tests," NBS Report 6754, 13 March 1961.

29. - T. L. DAVIS and R. H. DOHERTY, "Widely Separated Clocks with Microsecond Synchronization and Independent Distribution Systems," IRE WESCON Convention Record, 1960.