LORAN-C EXPANSION: IMPACT ON PRECISE TIME/TIME INTERVAL

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ABSTRACT

On 16 May 1974, the Secretary of Transportation and Commandant of the Coast Guard announced that Loran-C had been chosen as the navigation system to serve the U. S. Coastal Confluence Zone. At the present time, reliable CONUS Loran-C groundwave timing coverage extends westward only about as far as Boulder, CO. This paper illustrates the groundwave hyperbolic and timing coverage which will result from the planned CONUS expansion. Time frames are provided.
While not directly related to the subject of the paper, a status report on the planned reduction in Loran-C PTTI tolerances is presented.

INTRODUCTION

After several years of theoretical and practical evaluations of several navigation systems (Loran-A, Loran-C, Decca, and Differential Omega), the U. S. Coast Guard recommended to the Department of Transportation (DOT) that a single navigation system, Loran-C, could best serve the disparate navigation/positioning needs in the U. S. Coastal Confluence Zone (CCZ). The Secretary of Transportation subsequently approved the recommendation and, with the support of the Office of Telecommunication Policy and General Accounting Office, announced the choice on 16 May 1974. Follow-on announcements have described the expansion necessary to cover all of the CCZ.

LORAN-C EXPANSION

Figure 1 illustrates the existing Loran-C hyperbolic coverage in the CCZ. Notice that in Figure 1 the range limits are established for a receiver that requires a signal-to-noise ratio (SNR) of at least -10dB in order to acquire the Loran-C signals. While this is a limiting factor with the new, low-cost, civil-use receivers, it is not for a timing receiver. In timing receiver applications, of course, it is also not necessary to receive more than one station. Figure 2 is a projection of the groundwave timing coverage currently available in the U. S. In this case the range limits are based on my personal experience. I assume that signal acquisition is accomplished by identifying the Loran-C

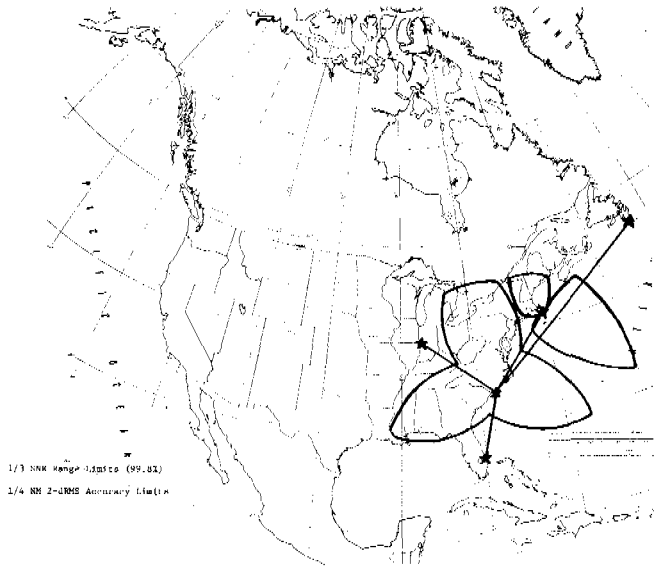

Figure 1. Existing U.S. CCZ Loran-C Hyperbolic Coverage

pulses visually on an oscilloscope. Third-cycle identification is assumed to be accomplished through the use of the Signal Strobe of an Austron 2000-C receiver to draw out the pulse. These assumptions, in short, give conservative range limits when compared with ranges available through the use of a synchronous filter, or knowledge of time and various delays to better than 5 microseconds so that signal acquisition and cycle identification can take place without "seeing" the signal. Figure 3 illustrates the approximate locations of the CONUS Loran-C stations after the expansion is completed. The stations are arranged in seven chains (including the existing North Pacific Chain). Again, the coverage shown is hyperbolic coverage for a civil-use receiver. Figure 4 is a schedule for the implementation. The first stage of the implementation, the U. S. West Coast Chain, was funded this fiscal year (FY). The next two chains to the North, the Northwest U. S. and Gulf of Alaska chains were originally scheduled for completion in late 1977, but due to the programmed completion of the Trans-Alaska Pipeline, the on-air date for all three of these chains was set as 1 January 1977 (assuming orderly approval of funds for the other two chains).

One of the new chains, the Cape Race/Caribou/Nantucket chain, shown on Figure 3, is not necessarily part of the expansion program. Since no additional funds are required to implement this chain other than the additional operating and maintenance expenses, and since it provides excellent coverage in a prime fishing area, such an operational chain may be established.

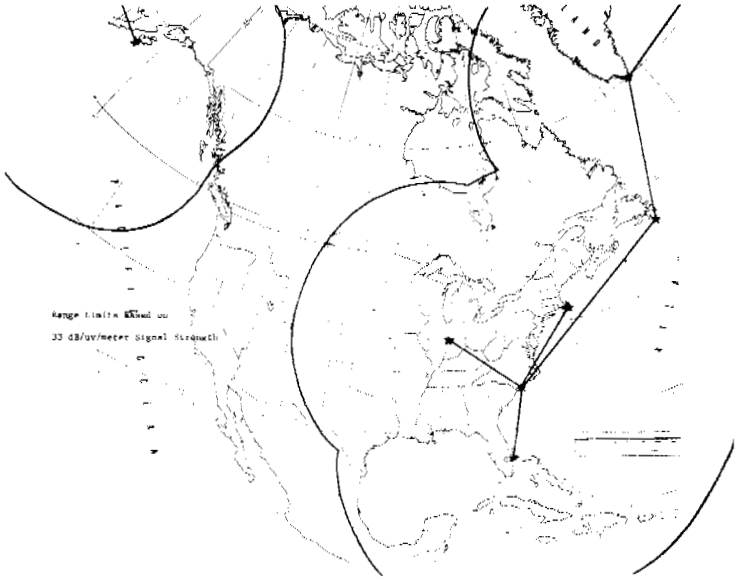

Figure 2. Existing U.S. Loran-C Groundwave Timing Coverage

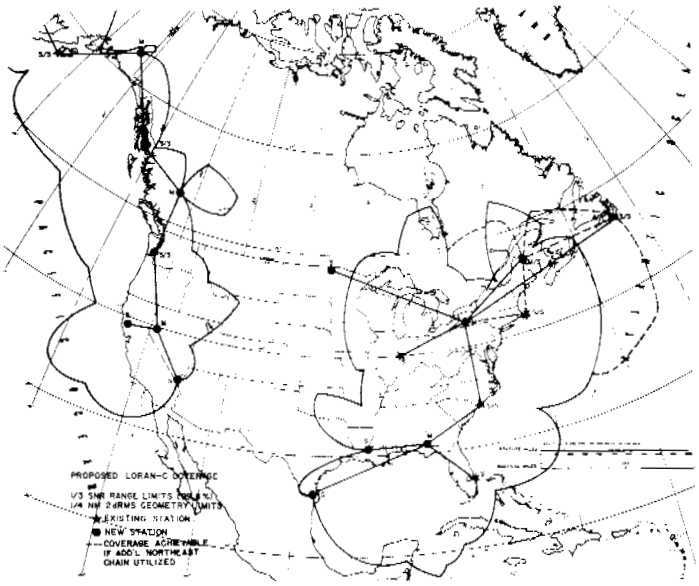

Figure 3. Proposed U.S. CCZ Loran-C Hyperbolic Coverage

CONUS TIMING COVERAGE EXPANDED

Figure 5 illustrates the timing coverage to be expected upon completion of the Loran-C CONUS expansion. There are at present no specific requirements to time any of the new chains. As a result, Figure 5, and the plans outlined in the following discussion are not final.

AREA	DATE
WEST COAST	1 JANUARY 1977
GULF OF ALASKA	1 JANUARY 1977
EAST COAST RECONFIGURATION	1 JULY 1978
GULF OF MEXICO	1 JULY 1978
GREAT LAKES	1 FEBRUARY 1980

Figure 4. Implementation Schedule For CONUS Loran-C Expansion

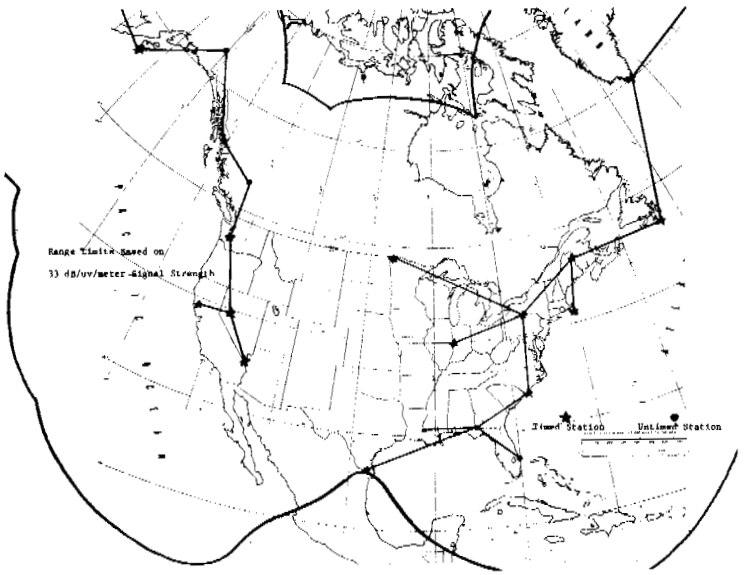

Figure 5. Proposed U.S. Loran-C Groundwave Timing Coverage

The basis for the timing coverage is that all points in CONUS must be within groundwave range of at least one station of a timed chain. The Coast Guard definition of a timed chain is a chain that has a specified time tolerance with respect to UTC(USNO). As can be seen from Figure 5, this basic timing criterion is met if only three of the CONUS chains are timed (East Coast, West Coast, and North Pacific). This would allow the use of a frequency offset in the other chains with attendant advantages in minimizing cross rate interference. These untimed chains could still

be used to transfer time between two points that are both within the coverage area of any one chain. In addition, they could be used in the absolute sense if a suitable Null Ephemeris Table were developed.

LORAN REPLACEMENT EQUIPMENT

While the expansion of Loran-C under the National Implementation Plan (NIP) is the Loran-C program receiving the most publicity, there is another program with less dramatic, but still real impact on PTTI. This program is the Loran Improvement Program (LIP).

The first major step in modernizing the Loran-C ground station equipment was the development of the AN/FPN-54 (COLAC) timer at the U. S. Coast Guard Electronics Engineering Center (EECEN) in 1969-1970. An improvement in the operational performance of COLAC-equipped stations was demonstrated in the period 1971-1972. This improvement was directly attributed to the COLAC's solid-state circuitry, modular maintenance philosophy, and operator oriented design. After noting the success of COLAC and realizing the extent and possible consequences of the remaining Loran-C problems, an ambitious ground station equipment improvement program was initiated at EECEN during early 1973. The general goal of this program was to improve the Loran-C chain operational performance while simultaneously reducing the personnel manning levels and equipment costs. Basically this program consisted of the development of a solid-state Loran Replacement Equipment (LRE) package which would replace the older generation timers and low signal-level pulse generating equipment and, in addition, modify the existing Loran-C transmitters.

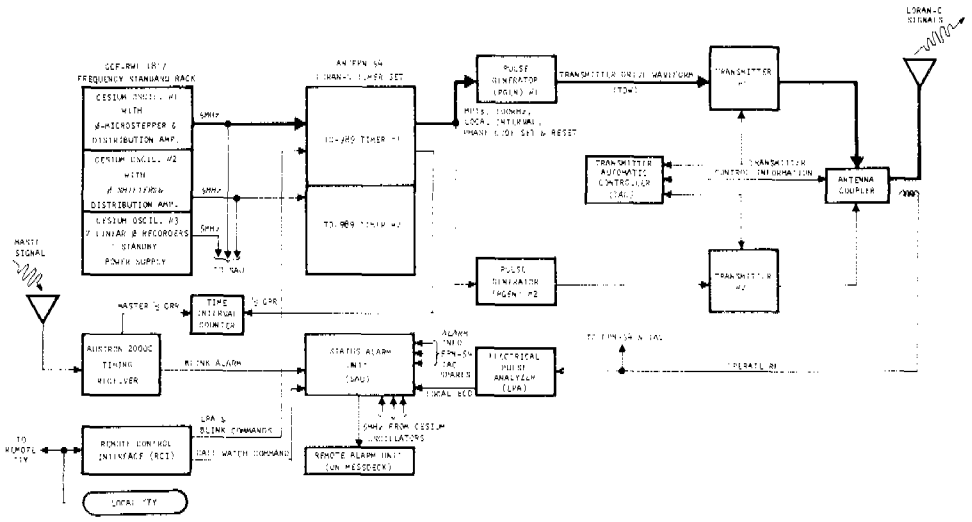

Figure 6. Loran Replacement Equipment

The LRE performs the basic Loran-C signal generation in a more precise, stable, reliable, and controllable manner than was possible with the older generation equipment. Figure 6 is a block diagram of a typical LRE configuration. A description of the major units which comprise the LRE package is presented herein.

Frequency Standard System. (Figure 7) This unit provides the 5 MHz and 1 MHz time base frequencies to the remaining LRE. The phase microstepper and phase shifters allow for precise correction of the cesium 5-MHz outputs. Two linear phase recorders provide continuous monitoring of the three cesium outputs.

AN/FPN-54 Loran-C Timer. The COLAC replaces the timing functions of the AN/FPN-38, 41, and 46 timers. The COLAC is a solid-state time generator whose basic function is to provide the signals necessary to drive the transmitters. More specifically, the COLAC provides the accurate and reliable timing waveforms which control the time of emission of the radiated Loran-C pulses.

Transmitter Control Set (TCS). The TCS replaces existing Transmitter Control Groups. The functions performed by the TCS are aiding in generation of a standard Loran-C pulse shape, monitoring the pulse amplitude, and automatically switching transmitters in the event of a transmitter failure. The TCS equipment units and their primary functions are:

(a) Pulse Generator (PGEN): Develops a transmitter driving waveform (TDW) from the timing signals received from the COLAC. The TDW is shaped within the PGEN to insure that the transmitter radiates a standard pulse shape with proper phase code and droop characteristics.

(b) Transmitter Automatic Controller (TAC): Automatically switches transmitters in the event of a failure of the operate transmitter. The TAC performs this function by monitoring the on-air Loran-C signal and the availability of the transmitter drive waveform. It also allows for manual switch of transmitters.

(c) Electrical Pulse Analyzer (EPA): Provides a capability for precise and unambiguous measurements of Loran-C pulse shape and amplitude. By appropriate programming, via front panel switches, the following measurements may be made: amplitide of pulse peak for any pulse, amplitude of half-cycle peaks (1 - 19) within the first pulse, and envelope-to-cycle difference (ECD) of the first pulse. All measurements are displayed on a front panel digital meter and provided at a rear panel connector in either analog or BCD form. In addition, the EPA generates a reference envelope waveform which is used in conjunction with an osciloscope and the operate PGEN to permit pulse analysis to be accomplished.

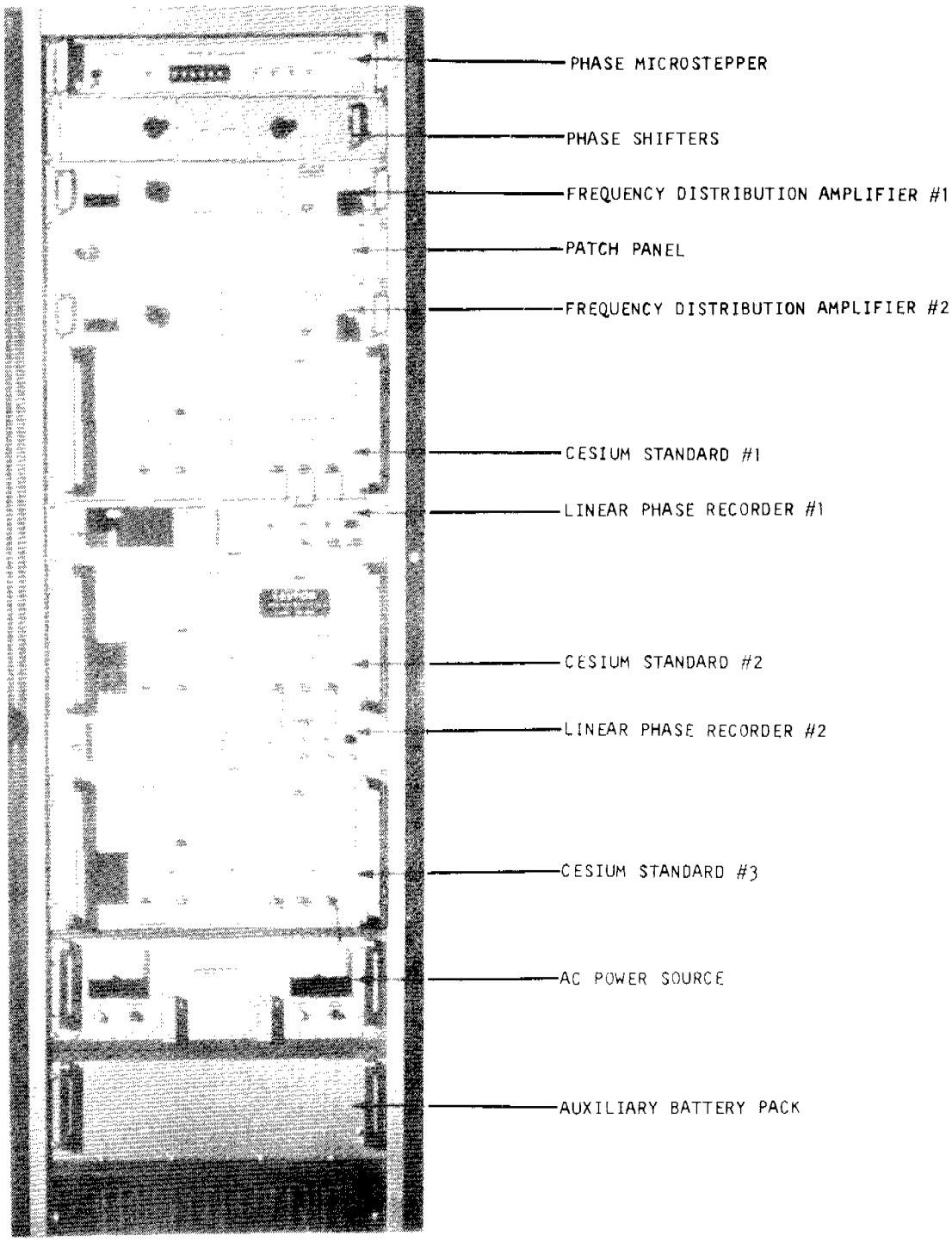

Figure 7. Frequency Standard System

Auxiliary Rack. The Auxiliary Rack contains units which perform the following functions:

(a) Status Alarm Unit (SAU): Provides a centralized alarm node and display position for all LRE alarm indications. In addition, the SAU monitors alarms for other important parameters (failure of 5 MHz, excessive ECD fluctuations, etc.) which affect the ability of the station to stay on-air in tolerance (Figure 8).

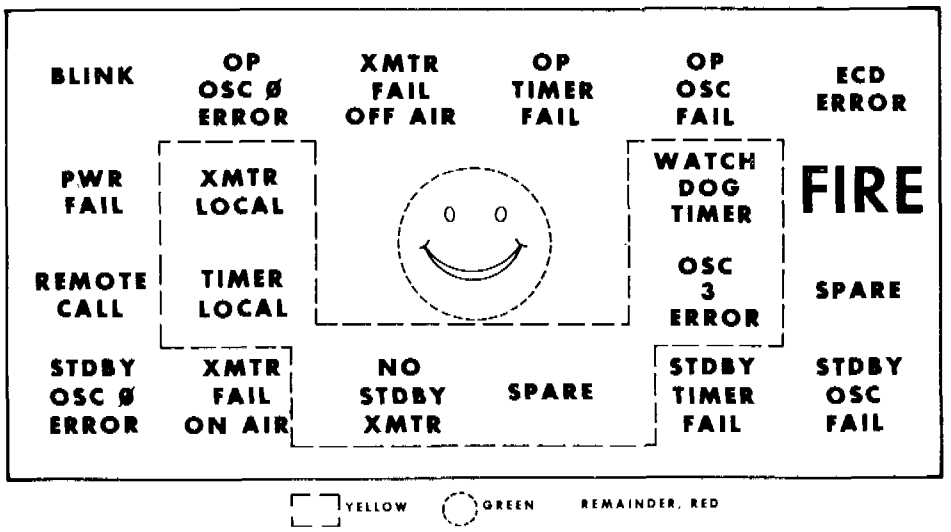

Figure 8. Status Alarm Unit

(b) Remote Control Interface (RCI): The RCI presently being installed with the LRE permits the following commands to be entered: local phase adjustments (LPA), start and stop blink, and call watch. The CALL WATCH command activates the audio alarms of the SAU to awaken the station watchstander in the event of an emergency. The RCI-2, presently under development, will expand the RCI capabilities, and permit a remote computer to control the LRE and perform all of the control and log-keeping functions for a Loran-C chain.

(c) Austron 2000-C Timing Receiver: Replaces the monitoring function of the older generation timers at secondary stations. A station "control number" is generated by comparing the receiver sampling strobe, tracking the master station, to the 1/2 Group Repetition Rate (1/2 GRR) generated in the COLAC at the secondary station.

RELIABILITY AND MAINTAINABILITY

One LRE design goal was to improve the reliability of the Loran-C

ground station equipment, and hence the system operational performance. Improved equipment reliability was achieved through careful design of the LRE units and overall system.

Reliability. The LRE was designed using high quality solid-state components. The printed circuit modules were conservatively designed, insuring that all components functioned at far below maximum ratings during normal operation. These efforts contribute to a very high Mean Time Between Failure (MTBF) for the LRE units, and thus to the high reliability of the Loran-C system. For example, under normal circumstances, there is no need to switch from the operate to the standby timers. This is in contrast to the operation of the older generation timers with weekly switches to perform preventative maintenance.

The complete LRE package is presently installed at LORSTA's Nantucket, Dana, Jupiter, and Estartit. Daily message reports on the performance of the U. S. East Coast Chain stations so equipped were evaluated at Coast Guard Headquarters. The overall performance of these stations for the period July 1973 through September 1974 is illustrated in Table I.

TABLE I UNUSABLE TIME BEFORE LRE VS AFTER LRE

	BEFORE LRE INSTALLATION (minutes)				AFTER LRE INSTALLATION (minutes)	PERCENT REDUCTION IN UNUSABLE TIME
LORSTA	1971	1972	1973	AVERAGE	1974	
JUPITER	889	506	623	673	317	52.9
NANTUCKET	530	479	991	667	231	65.4
DANA	858	367	716	647	336	48.1
TOTAL	2,277	1,352	2,330	1,986	884	55.5

Table I. Station Reliability Before and After LRE Installation

Maintainability. Use of the complete LRE package has significantly reduced the required maintenance. Table II illustrates the Loran-C equipment maintenance (excluding that for transmitters) required at LORSTA's Dana and Nantucket for periods before and after LRE installation.

LORSTA	BEFORE LRE AVERAGE 1971,1972, AND 1973 (hours) (Note 1)	AFTER LRE 1974 (hours) (Note 1)	PERCENT REDUCTION IN MAINTENANCE EFFORT
NANTUCKET	717	81	89.8%
DANA	877	35	96.6%
TOTAL			93.7%

NOTE 1. INFORMATION TAKEN FROM LORSTA'S REPORT OF LORAN STATION OPERATION AND ELECTRONICS ENGINEERING (CG-2899), MARCH THRU OCTOBER FOR YEARS INDICATED.

NOTE 2. TRANSMITTER MAINTENANCE NOT INCLUDED IN THIS TABULATION.

Table II. Station Maintenance-man-hours Before and After LRE

ALL CHAIN LORAN-C TIME SYNCHRONIZATION

A report on this program was presented at the 1973 PTTI Planning Meeting by LCDR Sherman. No significant changes have occurred in the program since that time save for an unfortunate delay of almost a year. This delay was caused by personnel shortages (witness the absence of LCDR Sherman at this year's meeting) and procurement delays. All of the required equipment is now in the procurement process, and in fact, most of the equipment has been delivered to our laboratory. The project to assemble the equipment in a rack, print suitable technical manuals, and ship the equipment to the stations has been initiated. We expect the first equipment to be in the field in the Spring of 1975. In the meantime, the Coast Guard, with the cooperation of the U. S. Naval Observatory, is attempting to maintain the values for (UTC(USNO)-Loran-C) within 5 microseconds for the timed chains. This will of course be much easier to accomplish when the equipment is in the field to make the published values independent of clock trips.

ACKNOWLEDGEMENTS

My thanks to LCDR G. R. Goodman and LT R. P. Oswitt for the information on the LRE.

QUESTION AND ANSWER PERIOD

MR. DOHERTY:

I wanted to correct any misimpression that I gave on ground wave signal at Boulder. First of all, we get strong ground waves from Dana. Also in that slide I was referring to the Carolina Beach master station and my comments were that the visible signal that you saw on the slide was sky wave, it was not ground wave. However, we do measure ground waves from Carolina Beach too.

LCDR. ROEBER:

I have been trying to keep my range on it very conservative.

MR. DOHERTY:

Yes, I'm sure your ranges are very conservative.

LCDR. ROEBER:

Where a signal would be visible, where it could be acquired from looking at the oscilloscope.

MR. DOHERTY:

Right. We do not have a visible ground wave there but we definitely have measurable ground wave at Boulder.

MR. OSBORN:

I have a continuing question on what is the position on installing precision timers throughout both the East and the West Coast chains? It is my understanding that up until rather recently you had not had cesium beam frequency standards in this.

LCDR. ROEBER:

That's not true. We always planned on cesium beam frequency standards in the West Coast.

MR. OSBORN:

And you have them on the East Coast, too?

LCDR. ROEBER:

The question is whether it has been timed or not, and there are various definitions of time. To my own personal definition and because of my temporary position, I guess the Coast Guard position on what a timed chain is, is one that has a tolerance with respect to UTC (USNO) and at the moment there is no requirement to maintain any such tolerance on any of the new chains.

MR. COSTAIN:

I would say I have no feeling of nationality in seeing these stations encroaching on Canadian territory. I'm very, very pleased to see it. I hope that they will be timed. In fact, they've relieved one of my worries in short how we could meet what I can see as a potential requirement for microsecond timing at the major airports.

LCDR. ROEBER:

Well, one thing to note. I showed those stations as untimed. Keep in mind that's untimed by my definition, meaning there is no tolerance with respect to the Naval Observatory. These chains could still be used for relative transfers between two points that are within range of the same chain. They could be used in an absolute sense if somebody wanted to develop a Null ephemeres that took intentional frequency offset into account.

MR. LIEBERMAN:

Ted Lieberman, NAVELEX.

I was wondering which of your chains had improved timing in the last year or so?

LCDR. ROEBER:

I meant to cover that. Here's OMEGA's chance to get back at us again. A paper was given last year at this conference by Lieutenant Commander Sherman, covering our plans for improving the timing capability or the monitoring capability, more than anything else, at the Loran-C transmitting station. I believe he probably gave a prognosis of the time that would take place. It hasn't.

One of the major reasons is personnel problems—personnel shortage. Witness the absence of Lieutenant Commander Sherman this year. Another problem is procurement cycles. Basically none of them have the equipment which will allow us to monitor the transmitting stations better and hence, to my mind even

though some of the graphs shown in Andy Chi's paper showed that the tolerance is 25 microseconds, recently, at least for the most part, we have been keeping the chains within 5 microseconds.

I don't think we can guarantee this until we have the approved monitoring capability and one of the major contributions to this would be, first of all, finishing the project which is at the radio station—our laboratory at the radio station right now here in Washington. To get the equipment into the field and secondly, satellite time transfer.

One of the biggest problems right now in reducing the tolerance and maintaining the tolerance of 5 microseconds is the necessity for clock trips and the inevitability that one week after the clock trip, the operating standard at the station concerned changes frequency.

Then your extrapolation is off for another three months till your next clock trip. I think satellite time transfers plus getting the equipment into the field are necessary. I would estimate the first equipment, intended to go to Okinawa, will be in the spring of next year, but that really won't improve things until such time that we have satellite time transfers and can do away with, or at least lessen, the number of required clock trips.

DR. WINKLER:

You mentioned the problem of cross chain interference and the possibility of reducing it by deliberately offsetting frequency. Is there any information available to the merits of this procedure as compared to exact timing relationship? I should say exact without offset, where the timing relationship can be used to gate out the interfering signals, which is easier if you do not offset your own chain.

LCDR. ROEBER:

Well, we have not examined that. It is certainly true that if you have an exact time relationship development of a cross rate blanker is easier. Unfortunately anything, including making a new rate structure, that has cost or complexity, adds complexity to a user's receiver and is looked upon with jaundice eye by the user.

However, simple development of a cross rate blanker under those circumstances would add cost to the user and we must first look at potential solutions that will not add costs to the user's black box. We don't really even have hard data on the improvement in cross rate interference. If we do put in a frequency offset, we have the reverse situation. We have what happened to the cross rate interference

problem when we stopped phase tracking or phase locking our secondary stations and started using cesium stations.

In addition to the cross rate interference problem, we also got into greater synchronous interference problems after the first of January, '72 when the UTC offset was eliminated. In effect we do have some data on what happens when we institute an intentional frequency offset but not on what happens in the case you described, sir.

DR. WINKLER:

There is, of course, the additonal problem that by destroying the easy or, let's say, the simple phase relationship between different rates, you also will prevent the utilization of stations from different chains which is now possible in the rho-rho mode.

LCDR. ROEBER:

You don't destroy that capability; you make it more complex.

MR. PICKETT:

Bob Pickett, Vandenburg Air Force Base, California.

What's the chance that you can be presumed upon to bring these stations up as they're built rather than waiting for the whole chain? Particularly, could you be so kind as to bring the three California stations up before 1977?

LCDR. ROEBER:

I sort of mentioned it. Perhaps there is some scepticism on my part of our ability to meet this schedule—never mind bringing the stations up before January 1, 1977.