N75 27190

DESIGN AND OPERATION OF A LORAN-C TIME REFERENCE STATION

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ABSTRACT

The purpose of this paper is to explore some of the practical questions that arise when one decides to use Loran-C in a time reference system. Since the subject of Loran-C PTTI has been covered extensively in the literature (see bibliography), a minimum of time is devoted to the concept and implementation of precise time on Loran-C. An extensive effort is made to provide basic, practical information on establishing and operating a reference station. This paper covers four important areas in this regard.

1. The design, configuration and operational concepts which should be considered prior to establishing and operating a reference station using Loran-C.

2. The options and tradeoffs available regarding capabilities, cost, size, versatility, ease of operation, etc., that are available to the designer.

3. What measurements are made, how they are made and what they mean.

4. The experience the U.S. Naval Observatory Time Service Division has had in the design and operation of such stations.

In general, an attempt is made to answer basic questions which arise when Loran-C is being considered for use in a time reference system.

INTRODUCTION

The purpose of this paper is to explore some of the practical problems that arise in using Loran-C in a precise-time reference system (PTRS). The use of Loran-C for timing has been covered extensively in the publications listed in the bibliography. For the purpose of this paper it is assumed that the intended user has satisfied himself that his timing requirements can be met using Loran-C and that his location is such that reception of Loran-C is possible. In general, this is relatively easy to determine; in a few cases it may require some on-site field testing. In any case, a sound design philosophy of determining specific requirements and examining and analyzing systems available to meet these requirements is an absolute necessity.

DESIGN, CONFIGURATION AND OPERATIONAL CONCEPTS

The design, configuration, and operational concepts are formed with the objective of creating a system which will produce consistently useful data. As design parameters vary according to system requirements in each individual case, a universal design is virtually impossible. The aspects common to all the systems dictate some design uniformity; however provisions must be made to allow for system modification where individual variations may become necessary. The design philosophy should be one of flexibility, allowing for a variety of contingencies.

Configuration or hardware concepts must also be extremely flexible to allow for unforeseen operating problems, variations in space available for equipment installation, or additional capabilities which may be needed. Operational concepts are the most important and least appreciated factor in putting a system into operation. The successful implementation of operational concepts is an absolutely necessary complement to the design and configuration concepts. Operational concepts deal with the people involved and thus are the factors which may well spell the difference between success or failure.

In developing these concepts, there are a number of questions which must be answered definitively if the design and operation of the station is to have a chance at being successful.

A. What types of data are required?

1. Is it necessary to know time-of-day, phase, or both?

2. Will measurements be relative or absolute?

3. To what accuracy do the quantities measured have to be known?

4. To what precision do the measurements have to be made?

The types of data required will dictate the type and complexity of equipment needed. The realization of absolute time-of-day to 5 microseconds with a precision of ± 0.1 microsecond requires more sophisticated techniques and equipment, for example, than that needed to determine relative phase to an accuracy of 10 microseconds with a precision of ± 1 microsecond. Obviously, any measurement requiring greater accuracy and precision requires more sophisticated techniques and equipment.

What is not obvious is the great difference in the degree of difficulty in making an absolute time-of-day measurement and making a relative phase measurement. This is true not only due to the inherent difficulties in making absolute measurements of any type but also due to the limitations which presently exist in the Loran-C time dissemination and monitoring scheme.

B. How current must data be, how often must they be reported and what means are available for reporting?

   1. Are data needed in real-time, hourly, daily or after-the-fact?

   2. Is a special reporting system necessary?

   3. What facilities are available for data communication?

The intended use of the data dictates when, how and if they are to be sent to a central collection point. If data are for use solely in-house at the site, there is no need for reporting. However, if the site is part of a network requiring real-time response capability for system synchronization, consideration must be given to designing a reporting system. This involves developing a meaningful recording format with uniform and consistent notation as to units, sign, etc., developing a standard message format with built-in data error checks and having a communication network available which is compatible with system needs.

C. Where is the station going to be located?

   1. Is the location within groundwave or skywave range of a Loran-C transmitter?

   2. What are the local signal reception conditions?

   3. What local primary power is available for operating the station?

   4. How much and what kind of space is available for equipment?

The location is a vital factor in the design and operation of a time-reference station using Loran-C. Groundwave reception versus skywave reception means the difference between units and tens of microseconds in system capability. Severe interference problems may require additional equipment and impose additional demands on operating personnel if consistent data are to be obtained. Poor regulation and frequent, extended outages of primary power are conducive to equipment breakdowns and data discontinuities. Limitations in installation space and operating enviornment may impose restrictions on the reference station design.

D. How will the station be initially synchronized and periodically checked for proper operation?

1. Can portable clock visits be made?

2. Is there an operational PTTI satellite system available?

3. Are there other timekeeping activities in that locale?

If a station is to be part of a coordinated reference system, some means of performing an initial synchronization and periodic checks must be available for verification of output data. If there are other timekeeping activities in the area or if access to a PTTI satellite system is available, the problem is minimal. If that is not the case, and the location is not on a routinely traveled portable clock route, clock synchronization can be a vexing and costly problem.

E. Who will be operating the station and taking data?

1. Will a highly qualified and interested scientist, engineer, or technician be in charge?

2. Will the station be operated by civilian or military personnel?

The success or failure of any field operation is dependent upon field personnel. This is particularly true in the case where timekeeping is a secondary objective only loosely related to the station's primary responsibilities. The qualifications, attitudes, and interest of those immediately involved in the system, coupled with the command or management structure, can be the factor that spells success in situations where the technical aspects are marginal or the factor that assures failure in situations that should otherwise be successful.

F. How will logistical support be handled?

1. Is local logistical support available?

2. Will all logistics be handled from headquarters?

If the station is located in an area where supplies and services are available, no problems usually exist. Location in areas where no local suppliers exist or transportation facilities are meager may require extensive preplanning if the logistical problems are to be overcome.

G. How will equipment maintenance and repair be handled?

1. Will maintenance be on a repair or replacement basis?

2. Will it be local or by a central depot?

3. Will it be on a component, card, module or equipment basis?

All equipment included in the system must be chosen on the basis of favorable, established performance and mean-time-before-failure characteristics. However, most equipment needs periodic maintenance and some equipment will eventually fail. How these problems are to be solved is dependent on several factors such as station location, logistical support available and the capabilities of local personnel. At one extreme, one might have highly qualified personnel in a location where expert help and adequate logistical support is available. In this case, local repair at the component level would be indicated. At the other extreme, one might have inept, disinterested personnel at a remote site with no support available. In this case, replacement of the equipment and repair at some central depot would be necessary. The decision on what approach is to be used must be made early in the design stage as the speed with which a system failure can be corrected is an important factor in deciding how redundant the system must be made.

H. How will training of site personnel be accomplished?

1. Will training be on site, on-the-job at each site or centralized?

2. Are operating personnel permanent or subject to reassignment on a regular basis?

The probability of success in designing and operating any system is directly proportional to the capabilities, interest and enthusiasm of the operating personnel. Good data can be obtained by skilled, interested personnel using a relatively poor system, while unskilled, disinterested personnel can turn the finest system into a shambles. Training can consist of anything from a formal, structured classroom and laboratory course to informal, on-the-job, self-instruction from an instruction manual. Whatever the means of instruction, motivation and interest are two factors which must be stressed. In cases where personnel are frequently reassigned, the problem is compounded by this repeated turnover and provisions must be made for periodic retraining.

DESIGN OPTIONS AND TRADE OFFS

The options and trade offs regarding cost, size, versatility, ease of operation, etc., available to the system designer are illustrated in Figure 1 and Table 1. Table 1 summarizes the most important characteristics of typical general equipment configurations. Figure 1 provides a breakdown of the equipment and costs for each configuration. Numer-

SUBSYSTEM	EQUIPMENT	BASIC	AUTOMATIC	AUTO/REDUNDANT
CLOCK	Clock	5-23K	5-23K	10-45K
	Microstepper			3,000
	Distribution Amp		1,500	3,000
RECEIVER	TRF Receiver	750		
	Auto Receiver		6,800	13,600
	Multifilter		650	1,300
	GRP Generator	850		
DISPLAY	Oscilloscope	2,000	2,000	2,000
	Counter		1,800	1,800
	Recorder		2,000	4,000
POWER	DC Standby		1,500	3,000
	Uninterruptible			2,600
MISC	Racks, etc.	200	800	2,500
TOTAL (EXCLUSIVE OF CLOCKS)		3,800	17,050	36,800

Figure 1. Loran-C Reference Station Equipment Costs

	Basic Manual	Basic Automatic	Automatic Redundant
Cost (without clock)	$3-4K	$15-20K	$30-40K
Size (inches of rack)	20-30	40-50	90-100
Versatility	Least	Better	Best
Ease of Operation	Difficult	Moderate	Moderate
Continuity of Data	Least	Better	Best
Skill Required	High	Moderate	Moderate
System Precision (microseconds)	±1-5	±0.1-1.0	±0.1-1.0

Table 1. Comparison of Typical Systems

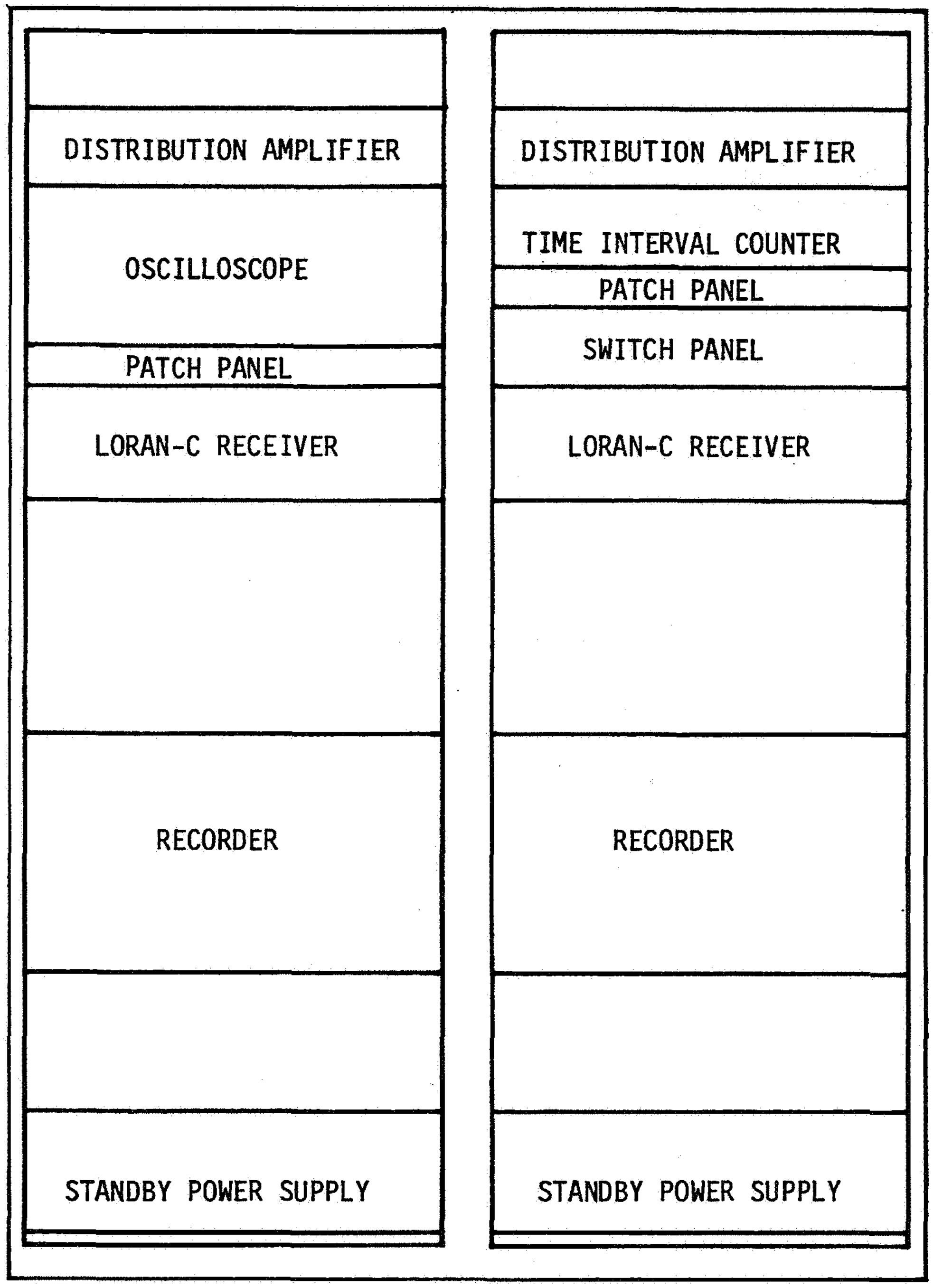

Figure 2. U.S. NAVAL OBSERVATORY PRECISE TIME REFERENCE STATION

ous other configurations are possible. A typical Naval Observatory PTRS is shown in Figure 2. As is generally true with most systems, improved operational capability means increased size and cost.

MEASUREMENTS

Typical measurements made in a Loran-C time reference system are simple. The required output data are time interval between the local clock and the Loran-C clock. Using corrections available from the Naval Observatory, (TSA Series 4), time relative to the master clock can be determined. Present state-of-the-art equipment is available for making time interval measurements with a precision of 0.1 nanosecond. This is several orders of magnitude greater than the usable limits of Loran-C transmissions; hence no measurement problems exist which are due to hardware limitations.

There are, however, problems of initially interpreting the meaning of the measurements. System delays (propagation times, antenna and receiver delays, tracking point locations, etc.) must be defined, measured and removed from the time-interval measurement to arrive at clock differences. The definition and measurement of these quantities are difficult and require special skills, techniques and equipment. Total uncertainties of several microseconds can exist in the measurements and calculations made to determine delays. Improper definition of tracking point and antenna characteristics can lead to half-cycle and full-cycle errors of five or ten microseconds. Final resolution of discrepancies usually involves field testing with a well calibrated system and portable atomic clocks.

USNO EXPERIENCE

The Time Service Division of the U.S. Naval Observatory has been responsible for the design, construction, and operation of a number of precise-time reference stations in the past seven years. Results have been mixed, with success or failure of any station being directly related to the organization and personnel operating the station. As one would expect, laboratories, whether government or private, directly involved in time-keeping are most adept at successfully employing Loran-C in time reference centers. Conversely, at locations where PTTI is a secondary effort, where highly qualified and interested personnel are unavailable, where personnel changes are frequent and where operational responsibility is spread over several organizations, attempts at consistent operation of the stations have met with numerous problems severely limiting their value and adversely affecting their data output. Even though much more effort is expended in putting those stations together and training station personnel, they experience significantly more discontinuities in data, more equipment failures and more operational problems than expected. Attempts to lessen the impact of these problems by building redundancy into the instrumentation have met with only limited success. More equipment in unfavorable circumstances seems to engender more equipment failures. With the exception of correcting obvious technical faults, improved operations at these locations depends entirely on what solutions can be found to the problems involving operating personnel idiosyncracies. It has become obvious that these problems are common to all organizations which seek to establish remote monitoring capabilities and are particularly acute in areas such as precise timekeeping where continuity and traceability are of primary importance.

CONCLUSION

An attempt has been made to highlight some of the problems encountered in using Loran-C in a precise-time system. Equipment exists to take full advantage of the timing capability inherent in synchronized Loran-C transmissions. Success at employing this equipment is dependent on operating personnel, organizational structure and system design philosophy. The concept of remote time-reference stations employing Loran-C has been proven workable; however, implementation is extremely difficult if proper conditions are not available.

BIBLIOGRAPHY

Rather than repeat what has been done many times before in regard to providing a bibliography of source material on timekeeping in general and Loran-C specifically, a selected number of publications are cited which provide a number of papers on these subjects within a single volume and/or specifically address the subject of remote Loran-C monitoring. The publications were chosen to provide a maximum amount of current information and extensive bibliographical material in a minimum number of volumes.

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