ALL CHAIN LORAN-C TIME SYNCHRONIZATION

LCDR H. T. Sherman
U.S. Coast Guard

ABSTRACT

A program is in progress to implement coordinated universal time (UTC) synchronization on all Loran-C transmissions. The present capability is limited to five Loran-C chains in which the tolerance is twenty-five microseconds with respect to UTC. Upon completion of the program, the transmissions of all Loran-C chains will be maintained within five microseconds of UTC.

The improvement plan consists of equipping selected Loran-C transmitting stations for greater precision of frequency standard adjustment and improved monitoring capability. External time monitor stations will utilize television time transfer techniques with nearby SATCOM terminals where practicable, thus providing the requisite traceability to the Naval Observatory.

Due to funding limitations, the program is being implemented in phases. The first phase comprises upgrading the East Coast, Central Pacific and Mediterranean Loran-C chains and outfitting the training facility. Subsequent phase(s) will upgrade the Northwest Pacific, North Atlantic and Norwegian Sea chains and implement synchronization in the North Pacific and Southeast Asia chains.

Equipment groups are being assembled and tested at the Coast Guard's Washington Radio Station Laboratory. Field installation is scheduled to commence early in 1974.

The paper discusses the time monitor equipment groups and the interrelationships with the ground station equipment. After a brief word on control doctrine, the remainder of the paper addresses forth-coming improvements to transmitting stations and how the time monitor and navigation equipments will complement each other resulting in improved service to all users of the Loran-C system.

INTRODUCTION

A discussion of the Loran-C system as a means for the dissemination of precise time and time interval (PTTI) is contained in the proceedings*, as is Loran-C time and frequency adjustment**.

This paper discusses existing Loran-C ground station equipment and the new time-monitor equipment groups being assembled and tested at the Coast Guard's Washington Radio Station. Current and future improvements in the navigation system will enhance the use of Loran-C for dissemination of PTTI.

Let us first take a look at a typical transmitting station as shown in form of a block diagram in Figure 1. The basic element of the system is the Loran-C timer set. Two timers are installed at each station. The timer performs the following functions.

- Generates Loran repetition rate from frequency standard input.
- Generates transmitter triggers and phase coding.
- Monitors Loran time difference between master-secondary pairs.
- Corrects the transmitted signal for propagation changes at the transmitting site.
- Provides alarms in event of system malfunctions or navigational tolerance errors.
- Provides a means of making phase adjustments to the transmitted signal to correct the navigation grid as directed by the control station.

The Control Indicator Group (CIG) provides operate/standby mode selection and signal routing. The Transmitter Control Group (TCG) generates low level Loran-C pulses from the triggers generated by the operate timer and provides operate/standby transmitter mode selection.

The transmitter then shapes and amplifies the Loran-C pulse to the rated power output. Peak output power is in the range of 160 to 3000 kw depending upon the equipment type and transmitting tower at the particular station. All transmitters

*C. E. Potts, "Precise Time and Time Interval (PTTI) Dissemination via Loran-C System", Proc. PTTI Strategic Planning Meeting, December 1970, pp. 32-54.

**C. E. Potts, "Time and Frequency Adjustment on the Loran-C System", Proc. PTTI Strategic Planning Meeting, November 1971, pp. 69-84.

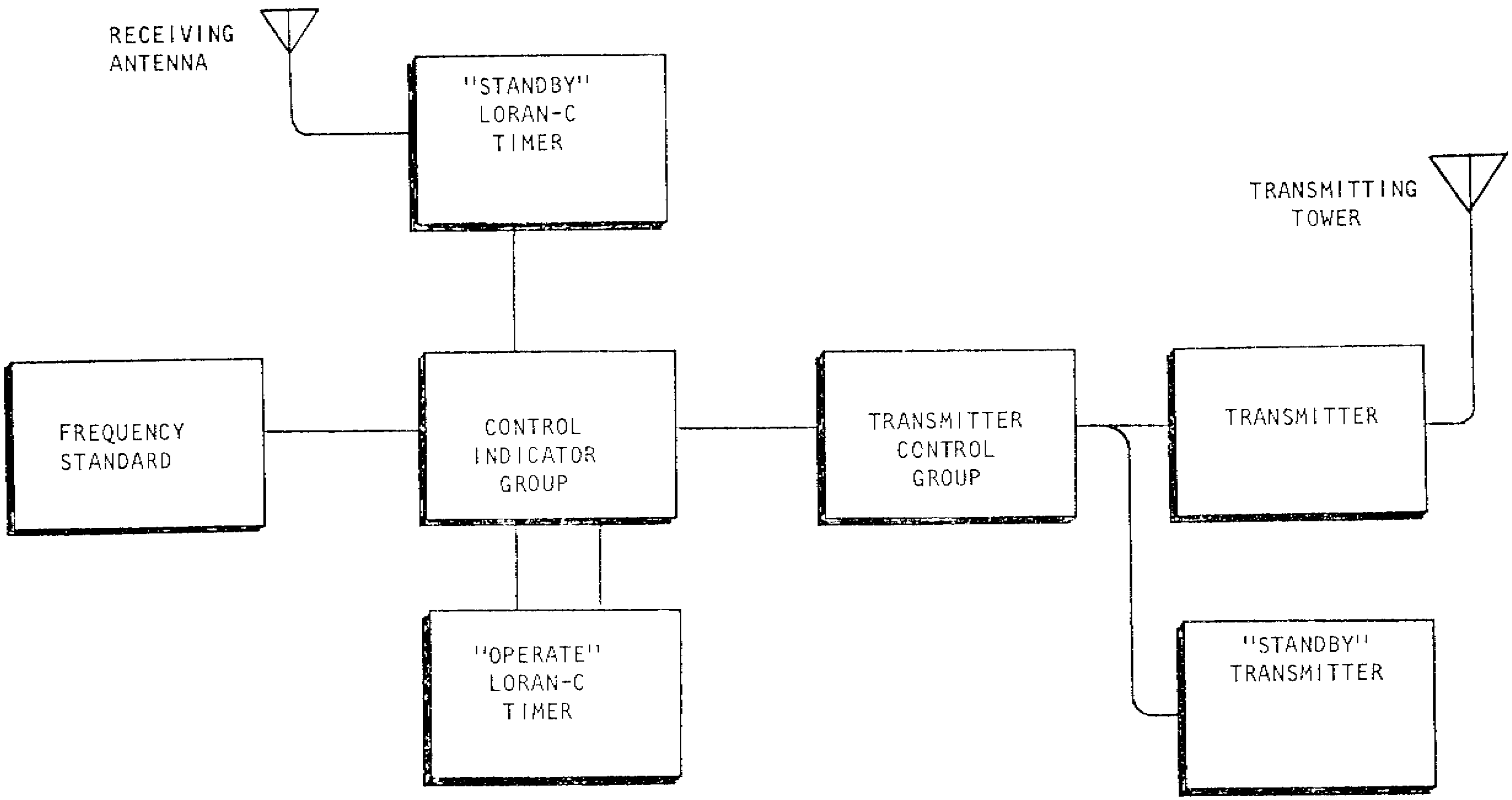

Figure 1. Loran-C Transmitting Station

presently in service are vacuum tube devices. A solid state high power transmitter is being developed under contract and, if successful, should be a substantial improvement in system reliability. The transmitter has traditionally been the weak link in the system.

Until recent years, the master-secondary time difference was controlled by electro-mechanical servo systems in the timers. The servo in the secondary-station timer actively tracked the master signal to maintain the prescribed time difference. This mode of operation, called "synchronized operation", resulted in the servo noise being transmitted on the secondary signal.

With the advent of atomic frequency standards, it was found that the timer servos could be turned off with a substantial improvement in stability of the time difference. This mode is called "free-running operation" and is now employed in all Loran-C chains. All transmitting stations are presently equipped with cesium beam frequency standards.

In the late 1960's, the stability and wide coverage of the Loran-C system were recognized as excellent qualifications for broad-scale dissemination of PTTI. Through cooperation of the U. S. Naval Observatory and the Coast Guard, several Loran-C chain transmissions have been synchronized to UTC (USNO). In order to initially implement the program, additional equipment was developed and installed at the master stations for the East Coast, Norwegian Sea, Central Pacific and Northwest Pacific Loran-C Chains.

The equipment added was a unit called a UT Synchronizer which interfaces with the station equipment and provides a local time reference. The UT Synchronizer utilizes the station frequency standard and performs the following functions.

- Generates and displays time of day.
- Generates and displays time of coincidence of UTC with the first master radiated pulse.
- Provides alarms in event of timing error.
- Provides Loran-C timer reset capability.
- Generates a 1-PPS transmitter trigger (Discontinued in 1972).

Figure 2 is a block diagram of the UT Synchronizer. The frequency standard input to each timer is independently controllable by a phase shifter to permit accurately positioning the transmitter trigger. This enables a fine adjustment

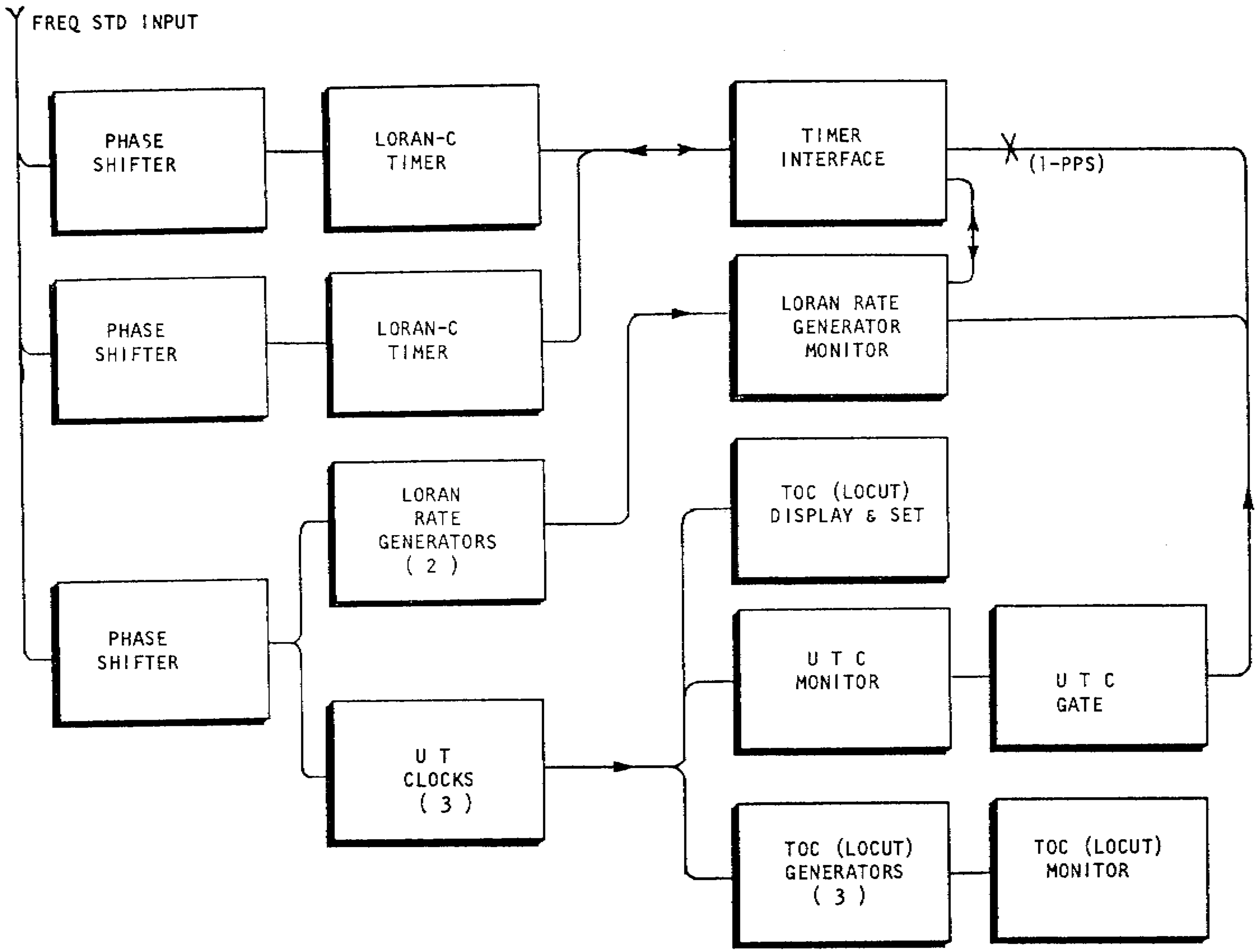

Figure 2. UT Synchronizer

to ensure that the first master pulse occurs at precisely the proper relationship at the time of coincidence (TOC). A third phase shifter controls the phase of the frequency standard input to two Loran rate generators. These independent rate generators are then compared to each other and the timers by the Loran Rate Generator Monitor. This unit also provides the capability of instantaneously resetting the timer to the UT Synchronizer. The remainder of the circuitry still in use comprises TOD clocks and the generation and monitoring of TOC. The UTC Gate was used to initiate a single pulse transmission each second. The 1-PPS transmission was discontinued in 1972, after the conversion of time scale to improved UTC.

The first UT Synchronizer was developed at the Coast Guard Electronics Engineering Center under project W-340 and was installed at Carolina Beach, the East Coast master station. This unit was subsequently installed at the master station in the Central Pacific chain after three improved models were constructed under project W-425. The major disadvantages of these UT Synchronizer equipments are.

- Cost
- Special operator training required
- Complex circuitry with no ability for "hands on" technician training.
- Requires timer modifications, therefore results in non-standard ground station equipment.
- Timer interface unit would require further modification for compatibility with future Loran-C timers.
- No time reference external to station.

Current developments are directed toward replacement of the aging timer equipments. A new generation timer has been developed for use at either Loran-C or Loran-A stations, and is commonly called "COLAC" for COmbined Loran A and C. The Loran-C version, the AN/FPN-54 performs all of the basic functions of the older equipments with one exception. The design is based on the free-running mode of operation, hence it does not have a time difference monitoring capability. A computer controlled monitor/control receiver is being developed under contract, and should be avilable in approximately three years.

Figure 3 shows the basic block diagram of the COLAC timer set. Except for operate/standby control and cross-timer comparison, all of the circuitry is

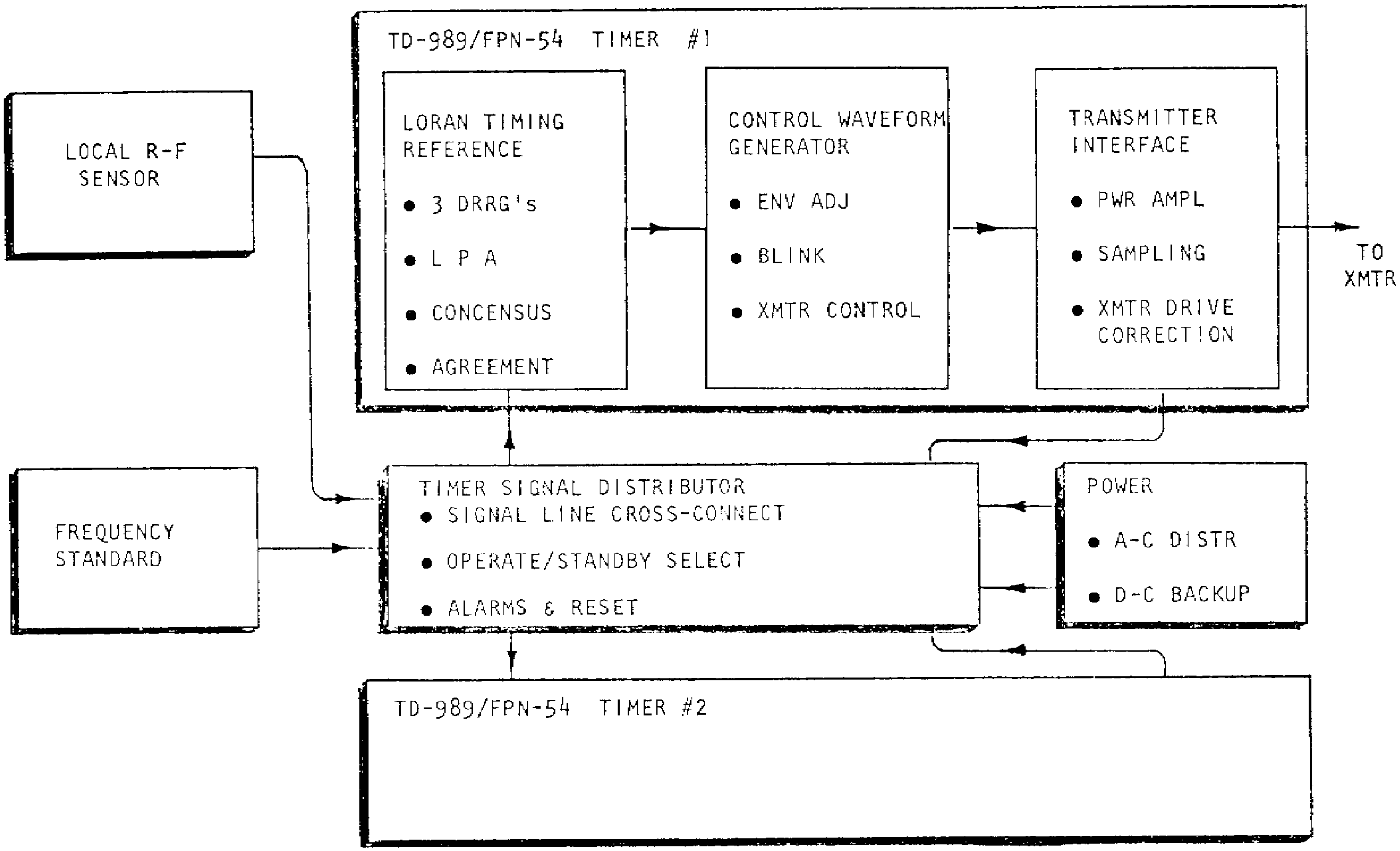

Figure 3. AN/FPN-54 (COLAC) Loran-C Timer Set

contained on fourteen plug-in printed circuit cards. The functions of the two TD-989/FPN-54 timers are:

- Loran Timing Reference
  - Three independent digital rate generators (DRRG)
  - Concensus voting of the DRRG's
  - Timer status indication
  - Cross-timer agreement monitor and reset
  - Programmable phase adjustment (Cycle timing adjustment)
- Control Waveform Generator
  - Transmitter control
  - Envelope adjustment
  - Blink control
- Transmitter Interface
  - Power amplification for transmitter drive
  - Transmitter drive correction
  - Sampling drive signal

The operate-timer contains a digital servo loop to compensate for changes in the local propagation characteristics.

The design of the COLAC timer is geared toward simplicity of operation and maintenance. Provisions have been made for remotely controlling many of the functions via communications link. This will eventually lead to reduced manning levels at the stations.

The initial COLAC installation at Estartit, Spain, has been in operation for over three years and has a remarkable record of only two failures, both in the power supply, during that period. The new-generation timers have been installed for some time at Bo and Jan Mayen in the Norwegian Sea chain, and recently at Carolina Beach, Nantucket, Jupiter and Dana of the East Coast chain. For an aggregate of over seven equipment-years of operation, there has been a total of about thirty minutes bad signal time directly attributable to COLAC. Most remaining stations will be COLAC-equipped within the next two years.

Of particular interest to all users of Loran-C is the development of a new transmitter control unit. This equipment permits individual control of each half-cycle of the transmitter drive signal by literally "building" the Loran pulse. Thus we will have pulse shape control to a precision heretofore unattainable. These new units have just been installed at Dana, Nantucket and Carolina Beach with future installations planned where pulse shape adjustment is particularly difficult due to transmitter type.

The improved stability and reliability of the navigation system suggests a potential for upgrading the PTTI capability as well. DOD has provided the first of two increments of funding to implement improved PTTI on all Loran-C chains. Under the improvement program, all master stations will be equipped for greater precision of adjustment of frequency and a self-monitoring capability. Where required, an additional time monitor will be established at a Loran-C transmitting site to provide the requisite traceability to UTC (USNO).

The following stations are in the program.

- Phase I
  - Carolina Beach — SS7 Master
  - Simeri Crichi, Italy — SL1 Master
  - Targabarun, Turkey — SL1 Time Monitor
  - Johnston Island — S1 Master
  - Upolo Point, Hawaii — S1 Time Monitor
  - Gesashi, Okinawa — SS3 Time Monitor
  - Training Center, New York
- Phase II
  - Cape Race, Newfoundland — SS7/SL7 Cross chain monitor
  - Angissoq, Greenland — SL7 Master

- Ejde, Faeroe Isles — SL3 Master & SL3/SL7 monitor
- St. Paul, Pribilof Is. — SH7 Master
- Attu, Aleutian Is. — SH7 Time monitor
- Iwo Jima — SS3 Master
- Sattahip, Thailand — SH3 Master & Time monitor

Figure 4 depicts the scheme that will be employed in most chains to monitor the timing of the chain. Satellite time transfer will establish the relationship between the SATCOM-terminal clock and UTC (USNO). The secondary transmitting station (Time monitor station) is then updated using passive television time transfer with the SATCOM terminal. The time monitor receives and compares the master transmitted signal to its updated clock.

The master station will also be equipped with timing receivers. One receiver will track the time monitor signal, while the other will track the master's own radiated pulse. Thus, should the master station have a failure of both timers, or some other such catastrophic failure, it will have the capability of re-establishing the relationship to UTC without external assistance.

The block diagram for the time monitor station is shown in Figure 5, and comprises the following major elements.

- Local signal switched attenuator/blanker. Prevents overdriving timing receivers during local transmitting interval.
- Timing receivers. Provides phase-shifted 1 MHz and 1-PPS which are coherent with the signal being received.
- Multicoupler. Signal conditioning and interference rejection.
- Recorders. Provide permanent record of local frequency standard minus received signal.
- Time interval counter. Provides means of comparing various frequency and signal sources.
- Control unit. Selects source for time interval counter. Provides alarm in event of timing error. Visual display and monitor of TOC.

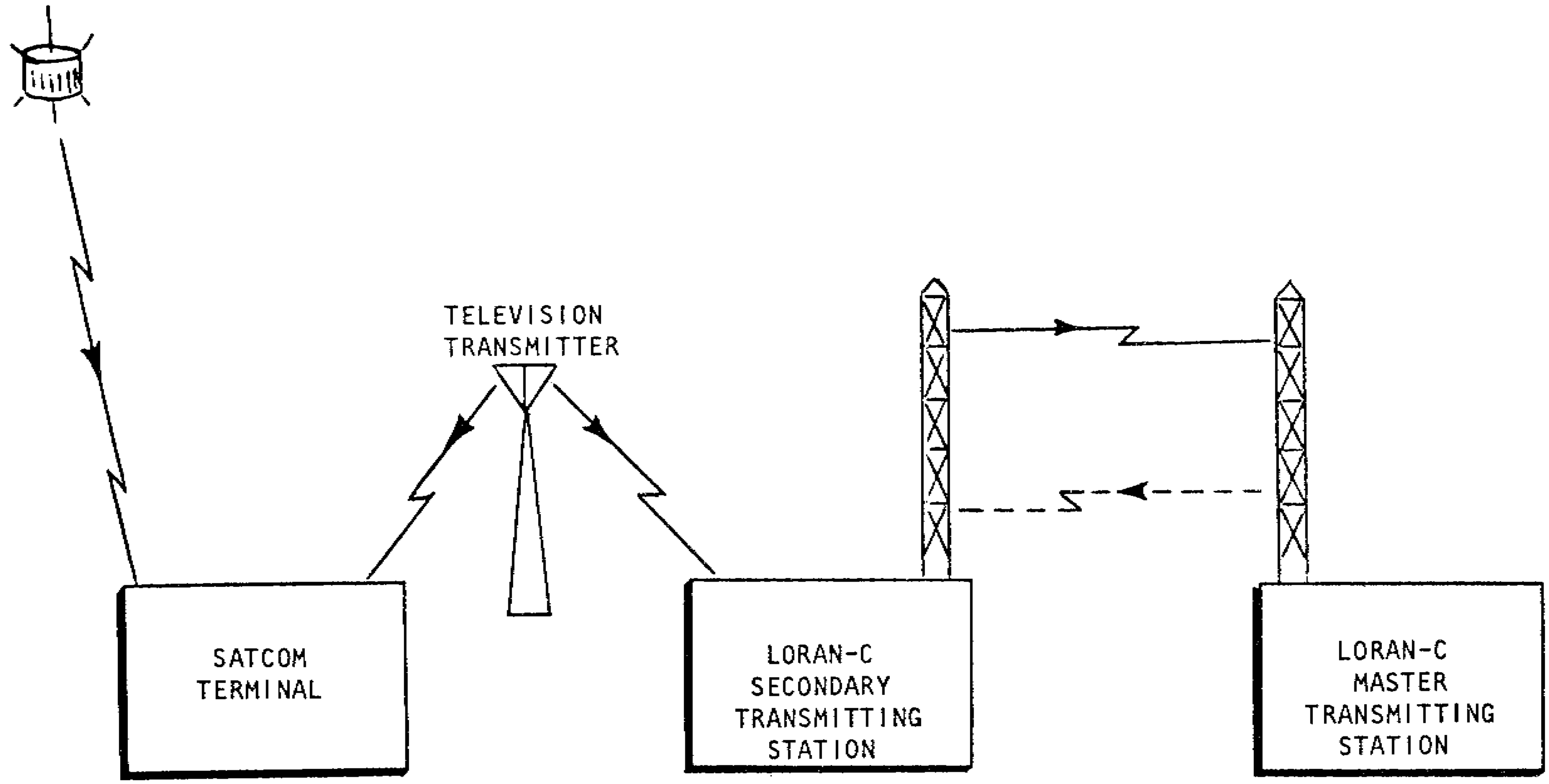

Figure 4. Transfer of UTC (USNO) to Loran-C Chain

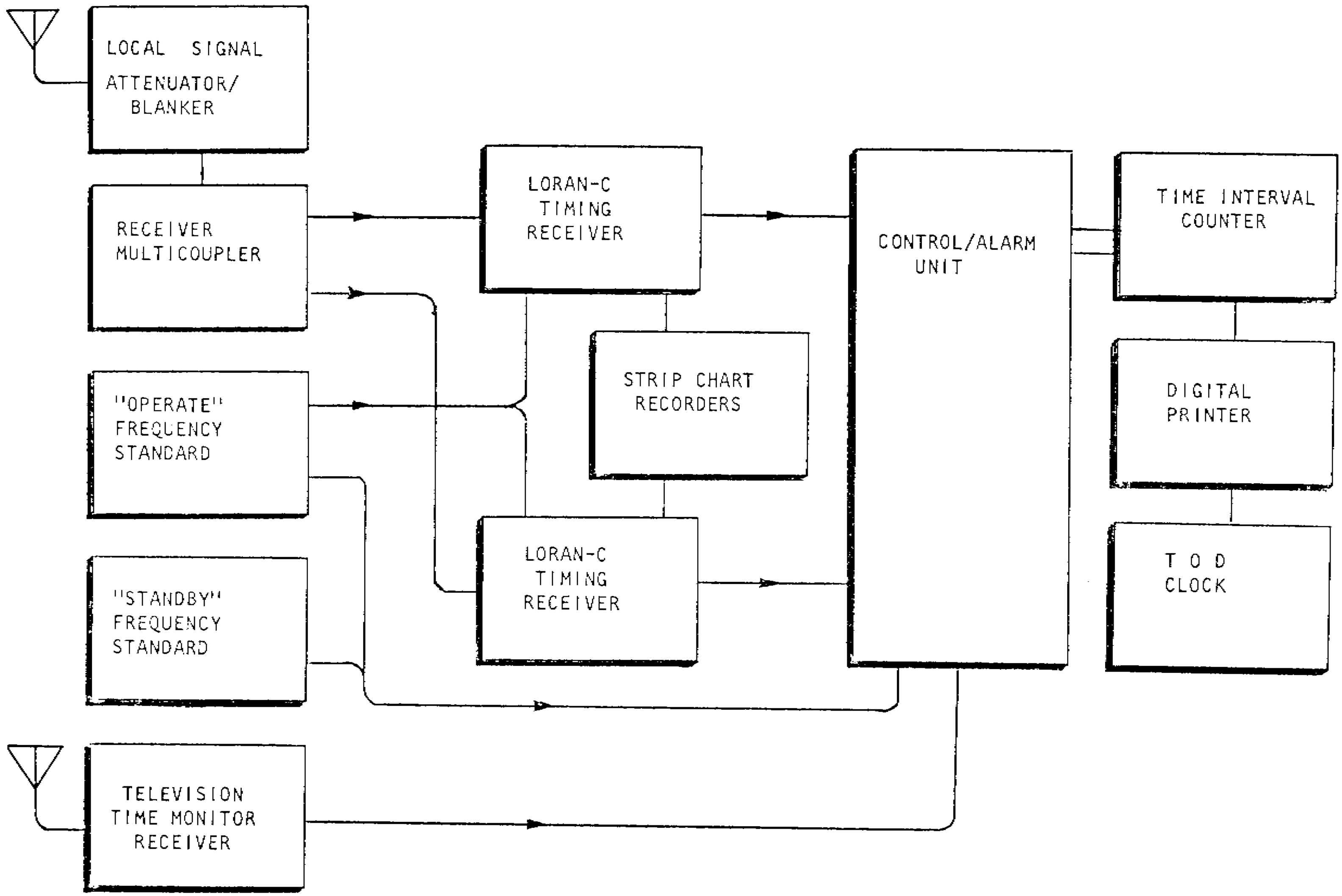

Figure 5. Timing Equipment Cabinet

- Digital printer & TOD clock. Provides permanent record of time interval counter reading and corresponding time of day.

- Television time monitor. Provides an output coincident with a specific TV synchronization pulse for passive TV time transfer with SATCOM terminal.

Experience has shown that the fine frequency control (C-field adjust) of the cesium beam frequency standard is rather coarse when attempting to maintain tight control of the frequency offset of Loran with respect to UTC (USNO). To obtain an improved means of adjusting frequency offset, each master station will be furnished with two phase microsteppers*. These units enable adjusting the frequency offset in increments of one part in 10^{14}.

The high resolution available with the phase microstepper has given rise to a technique which will be evaluated in the near future. The COLAC timer contains circuitry which monitors cross-timer agreement and alarms if the difference between timers exceeds twenty nanoseconds. The scheme which will be studied is shown in Figure 6, and may be the configuration in the future. The primary-frequency-standard/phase-microstepper combination is used as the input to the "operate" TD-989/FPN-54. The standby timer, however, uses the backup frequency standard-microstepper. This configuration would provide continual comparison of the two frequency sources within the twenty nanosecond window. Should the on-line equipment fail, the station would simply change timers (a single pushbutton operation) and resume transmitting without loss of time.

Let us now take a look at the control problem. Stations which are presently contributing to the Loran timing control function are listed below.

- SS7 directly observed by Naval Observatory

- SS7-SL7 measurement made at Cape Race. Reported by daily message.

- SL3-SL7 measurement made at Ejde. Reported by daily message.

- SL1-SL3 measurement made at BIH and II/P in Geneva. Periodic summary provided by message.

*Precise Frequency Offset Generator, model 2055 mfd. by Austron, Inc.

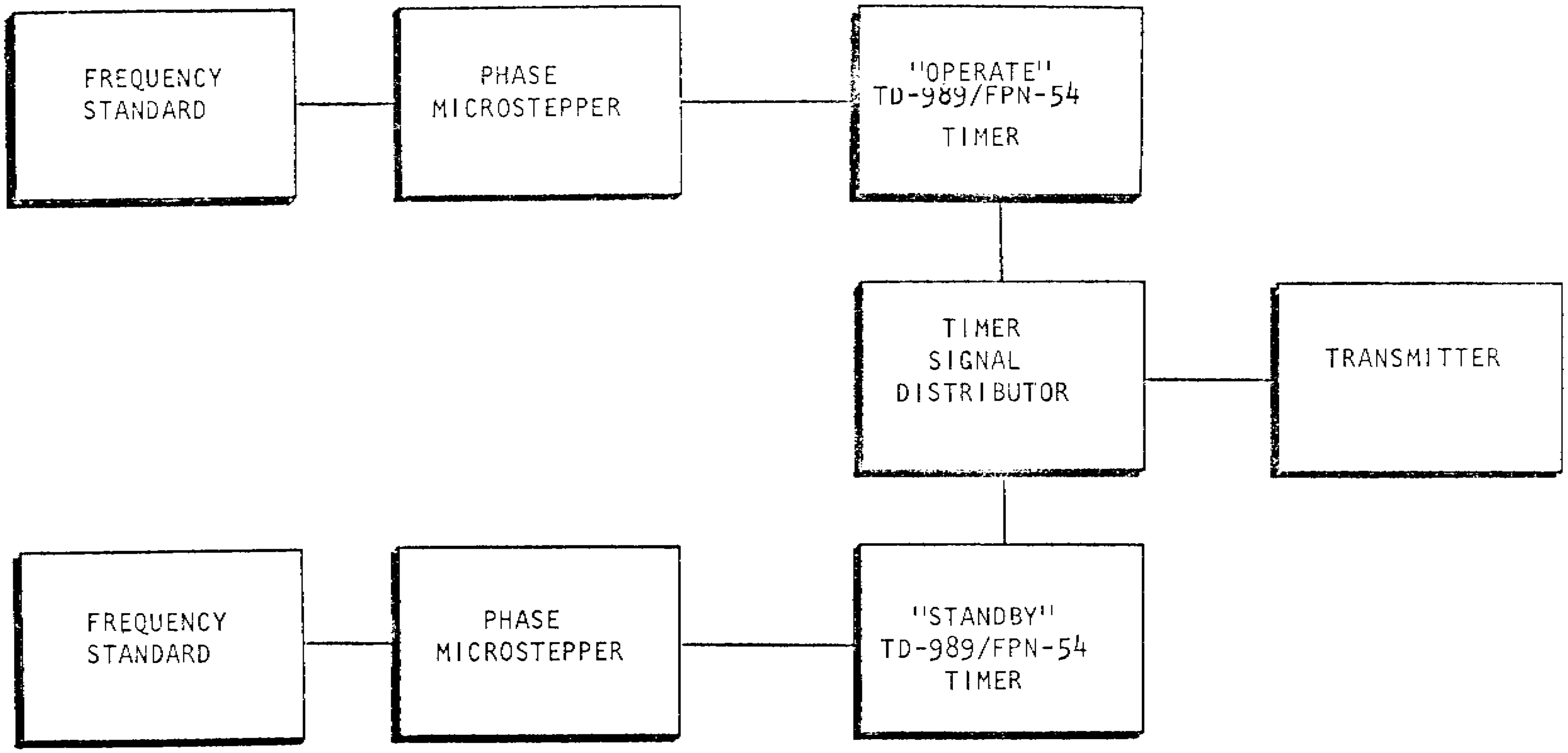

Figure 6. Loran-C Transmitting Station, Proposed Configuration

- S1 monitored by US NAVASTROGRU DET "C". Reported by daily message. UTC (USNO) update from SATCOM terminal at Helamano and portable clock.

- SS3 monitored by USCG LORMONSTA Fuchu. Reported by daily message. UTC (USNO) update by portable clock. Monitor data also provided to USNO by SATCOM terminal at Futenma, Guam.

Based upon the data from these various reports, the Observatory computes the daily phase values, which are then published in Time Service Announcements. Adjustments of operate frequency standards at master stations are directed by Coast Guard Headquarters with the concurrence of the Observatory.

With the availability of UTC (USNO) at the SATCOM terminal, hence at the time monitor, this rather lengthy process could be reduced to a local control function. In fact, local control would be required to implement the mini-step adjustment method which has been suggested*. Although requiring some conventional operating technique of the navigation system, the following is considered to be a practicable control doctrine. This could be implemented with minimal additional equipment, namely, phase microsteppers at the time monitor with additional 1-PPS dividers.

- Time monitor uses "new" 1-PPS source for time transfer from SATCOM terminal.

- Time monitor adjusts own microstepper for zero offset.

- Master adjusts microstepper for zero offset with respect to time monitor as directed by the monitor.

- Remainder of secondary stations maintain relationship to master by local phase adjustments.

The time monitor station would then report the change in frequency offset. An alternate, and perhaps more palatable, method would be for the time monitor to recommend the intended change, but not enter it in the system until concurrence was received from higher command.

*Potts (op.cit.)

The All Chain PTTI Improvement Program depends to a large degree upon the traceability of the time monitor station to UTC (USNO). If satellite time is not available at the SATCOM terminal, or cannot be transferred with an acceptable accuracy, then we will have to continue with the burden of the portable clock. In either event, I am sure that we can meet the goal of maintaining all Loran-C chains within 2.5 microseconds of UTC.

QUESTION AND ANSWER PERIOD

LCDR. SHERMAN:

Are there any questions?

QUESTION:

Your slide on the monitor system didn't show anything for the Alaska chain. I was just wondering, how do you currently monitor the SH-7?

LCDR. SHERMAN:

The Alaskan Chain is not presently timed. I believe that there are some — I know that there are several users. The Observatory has been working on the problem. However, the chain itself is not equipped with a UT synchronizer.

DR. REDER:

Yes, Mr. Lavanceau.

MR. LAVANCEAU:

In regard to the Alaskan Loran-C chain, we believe that in about two weeks from now we may be able to put that chain on time. In other words, asking the Coast Guard to make the time adjustment to the chain which would result in a step of about 15 milliseconds. The monitoring will be done by three different organizations, six stations, located all over Alaska.

In regard to monitoring some of the chains as far as the Mediterranean Loran-C chain, your slide shows that the monitoring was done by the Paris Observatory, (BIH) and through the H. P. Lab in Geneva. In addition, we use monitor data from the USNO in order to detect the timing variations of the North Atlantic chain. Also for the Northwest Pacific we use about 6 or 7 different monitoring sites in addition to the Fuchu site.

DR. REDER:

Any more questions?

Mr. Smith.

MR. SMITH:

Thank you, Mr. Chairman.

I do not wish to ask a question, but if I may for a moment speak as the Chairman of the Directing Board of the BIH, may I say how dependent we are upon the Loran-C system in order to form the international scale of atomic time. We do very much greatly appreciate the cooperation of the U. S. Coast Guard organization in trying to meet these very specialized needs of precise timing in order that the independent atomic time scales may each contribute towards the international scale.

Since Admiral Pearson was present at one of the CCDS meetings, there has indeed been a full understanding by the Coast Guard of this additional responsibility, and I would like to place on record our appreciation of all that has been done.

Thank you.

DR. WINKLER:

Dr. Smith's comments prompt me to add some comments to the discussion which we had yesterday and also to this paper here.

Some users have experienced troubles in picking up time absolutely with sufficient accuracy, and I refer back to Dr. Smith's comments yesterday.

Now, one of the problems in many such cases is that the geodetic position is not known accurately enough. If you do not know your geodetic position, or if there is a question about on which datum that position is, you cannot expect, of course, to get absolute time to within one microsecond.

There is one good way to circumvent that. If you have capable operators in the station, what you do is you determine your Loran Hyperbolic position with the same timing equipment which you use to pick up time. You make difference measurements of time of arrivals from every station of the chain that you can get, and you compute (these programs are available) your Loran position.

If you use, then, that position to compute your absolute time delay, you will find a significantly greater agreement with portable clock calibrations than otherwise.

Thank you.

CMDR. SHERMAN:

Just to add a little bit to Dr. Winkler's comment there. We have at headquarters several programs which will give us the all seawater transmission time, or propagation time from the transmitting station to the monitoring point.

If you know your geographic position, I would volunteer my services — let us know where you are, and what station you want to receive, we will not only give you the baseline distance in microseconds, but we will also give you a computer printout which will tell you how to correct for the terrain between you and the transmitting station.

This additional factor is very important. It is called Additional Secondary Phase Correction, and as a matter of fact we have some little slide rules, which, if you don't want the whole big computer printout, we can send you.

DR. REDER:

Any more questions?

May I ask one myself?

You mentioned that reliability of the transmitter towers is occasionally some problem — how serious is that?

CMDR. SHERMAN:

Well, as with any high powered transmitting equipment, you have equipments that you are really pushing to their extreme.

We frequently have trouble at Cape Race because of lightening. Now, there is not a thing we can do about that. We have been fighting it for years, static drain resistors, other types of suppressors.

DR. REDER:

How important is this? Does it appear weekly, daily, monthly?

CMDR. SHERMAN:

Again, it depends upon the conditions, the age of the equipment, the local conditions, the technicians that we have at the station.

Normally, our signal availability time is better than 99 percent of the time.

DR. REDER:

Another question or comment?

(No response.)