X-573-71-148
PREPRINT

NASA TM X- 65515

OPERATIONAL CONSIDERATIONS FOR THE USE OF LORAN-C SKYWAVES FOR TIME SYNCHRONIZATION

WILFRED E. MAZUR, JR.

APRIL 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-573-71-148

OPERATIONAL CONSIDERATIONS FOR THE USE OF LORAN-C SKYWAVES FOR TIME SYNCHRONIZATION

Wilfred E. Mazur, Jr.

Data Handling and Display Branch
STADAN Engineering Division

April 1971

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

OPERATIONAL CONSIDERATIONS FOR THE USE OF LORAN-C SKYWAVES FOR TIME SYNCHRONIZATION

Wilfred E. Mazur, Jr.

Data Handling and Display Branch
STADAN Engineering Division
Goddard Space Flight Center

ABSTRACT

Although Loran-C has been an operational navigation system for many years, the capability of near-world wide time synchronization has only recently been explored. Night time sky-wave reception of up to 15,400 Km has been achieved with time synchronization to better than 25 microseconds. Good results at such long distances, however, put much demand on receiver performance and operator technique.

This paper will attempt to detail many of the common problems and mistakes which can arise in Loran-C timing, and present some solutions which have proven most effective in the past.

CONTENTS

	Page
ABSTRACT	iii
I. INTRODUCTION	1
II. MODERN LORAN-C RECEPTION	6
III. SKY WAVE PROPAGATION	11
IV. CYCLE IDENTIFICATION OF SKY WAVE SIGNALS	15
A. High Amplitude Cycle	15
B. First Cycle Identification	15
V. RECEPTION UNDER HIGH NOISE CONDITIONS	20
VI. NON-SYNCHRONIZED LORAN-C CHAINS	26
VII. THE SYNCHRONOUS FILTER	29
VIII. OPERATIONAL CONSIDERATION FOR LORAN-C TIMING	31
APPENDIX A	33
APPENDIX B	37
TIME SERVICE ANNOUNCEMENT	38

PRECEDING PAGE BLANK NOT FILMED

ILLUSTRATIONS

Figure		Page
1	Transmission Sequence for Typical LORAN-C Chain	1
2	A Typical LORAN-C Pulse	4
3	Phase Codes for LORAN-C Transmitters	5
4	Simplified Block Diagram of a LORAN-C Receiver	7
5	Phase Coded and Uncoded Pulses	8
6	Sky-Wave Hop Geometry	11
7	Delay per Hop for Sky Wave Reception	12
8	Relative Amplitude of Sky-Wave Signals	14
9	Two Sky-waves of Equal Amplitude Separated by approximately 70 Microseconds	16
10	Two Sky-Waves Separated by approximately 70 Microseconds — Early Hop 12 db Down	18
11	Notch Filters Tuned to 100 KHz	23
12	Balanced Phase Decoding	25
13	Time Transfer via Two LORAN-C Chains	26
14	Simplified Diagram of a Synchronous Filter..................	30
15	Synchronous Filter Improvement as a Function of Averaging Time	36

TABLES

Table		Page
1	Group Repetition Periods	2
2	RTC's	35

OPERATIONAL CONSIDERATIONS FOR THE USE
OF LORAN-C SKYWAVES FOR TIME SYNCHRONIZATION

I. INTRODUCTION

Loran-C is fundamentally a low frequency hyperbolic radio-navigation system operated and maintained by the United States Coast Guard. The present Loran-C system is the result of an evolution from several radio-navigation systems, most notably Loran-A, which operates in the 1800-2000 KHz frequency range. In 1957 the first Loran-C system (chain) became operational, providing highly accurate long-range navigation for the East Coast of the United States. At the present time there are eight such Loran-C chains located around the world.

Each Loran-C chain consists of three or more individual transmitting stations all transmitting on exactly the same frequency - 100 KHz. The emissions from each station within a chain are time multiplexed: one station, designated the "master", transmits its signal first, followed sequentially by the other "slave" stations. The slave stations transmit in a prescribed order; slave-w, followed by slave-x, slave-y, etc. The delay between the master's transmissions and each slave is accurately known and maintained. The transmitted signals are shown schematically in Figure 1.

Each station transmits a group of eight pulses, with the master transmitting an additional identifying ninth pulse. The beginning of each pulse is separated from the next pulse in the group by exactly 1 millisecond. The master's ninth identifier is delayed 2 milliseconds from the eight pulse. The transmitting sequence (M-S-S-S) is repeated at a rate unique to each chain. This unique

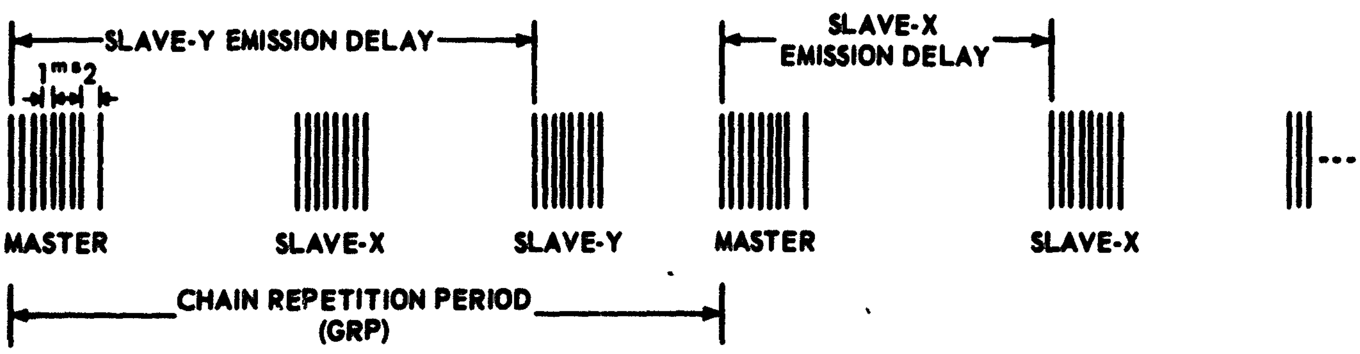


Figure 1. Transmission Sequence for Typical LORAN-C Chain

rate and the exact delay between the master and each slave (emission delay) are the only differences between the Loran-C chains. The 48 possible repetition rates are tabulated in Table 1 according to the period (GRP) in microseconds. The terminology "Basic PRR" and "Specific PRR" in Table 1 are carry-overs from Loran-A systems and refer to methods for generation of these rates which are now obsolete. This terminology is still often used to designate a particular Loran-C chain and its GRP; for example the East Coast chain has a GRP of 99,300 microseconds and is sometimes referred to as simply SS-7.

The delay between the master and each slave is the "emission" delay. The delay is chosen for each slave so that the pulse groups from the stations will not over-lap regardless of the reception point. The emission delay is always the propagation delay from the master to the slave plus an integral number of milliseconds, called the "coding" delay.

All of the pulses transmitted by both masters and slaves are identical in that the envelope of the 100 KHz pulse follows the equation:

$$F(t) = t^2 E^{-\alpha t}$$

where

$$\alpha = 2.76 \times 10^{-4}$$

Table 1

Group Repetition Periods

(microseconds)

SPECIFIC RATES	BASIC RATES					
	SS	SL	SH	S	L	H
0	100,000	80,000	60,000	50,000	40,000	30,000
1	99,900	79,900	59,900	49,900	39,900	29,900
2	99,800	79,800	59,800	49,800	39,800	29,800
3	99,700	79,700	59,700	49,700	39,700	29,700
4	99,600	79,600	59,600	49,600	39,600	29,600
5	99,500	79,500	59,500	49,500	39,500	29,500
6	99,400	79,400	59,400	49,400	39,400	29,400
7	99,300	79,300	59,300	49,300	39,300	29,300

The value of K is chosen to provide a peak 72.5 microseconds after the beginning - (the eight cycle.) In practical experience, however, this envelope is only maintained from the first 5-6 cycles so that the eighth cycle may not actually be the peak. The unusual (Figure 2) shape achieves a relatively sharp rise-time while keeping frequency components outside the 90 - 110 KHz band 20 db down.

For reasons to be discussed in Section V these pulses are phase coded - that is, the phase of the 100 KHz carrier in each pulse is made to start positive (+) or negative (-) according to a prescribed code. This code is shown in Figure 3 as plus and minus signs and has a period of two GRP periods. Also, as shown, the codes for the master is different than the code for all slaves.

There are two important requirements on such a system to assure reliable navigation:

1. The emission delay (the delay between the Master and the Slave Transmission) must be accurately maintained (to approximately 0.1 microseconds).

2. The pulse shape, particularly the slope of the first few cycles must be kept uniform. This is necessary so that a reliable determination of the beginning of the pulse can be made (cycle identification).

Both of the above requirements make this system useful for time dissemination. A practical solution for the first requirement was to allow each station to transmit its own group of eight pulses independently. The (GRP) repetition rate at each station was determined by highly accurate frequency standards (originally crystal oscillators and now cesiums).

It is the job of the slave stations to monitor the Master stations transmissions and insure that its own epochs ("slewing" if necessary) occur the prescribed time after the Master's.

The transmission of such epochs at a highly stable rate provides the basis for time dissemination providing the Master's transmissions could be synchronized to a recognized time reference - UTC (USNO). In 1955 this capability was explored. The East Coast (U.S.) chain, then transmitting at the 100 MS repetition rate, synchronized the Master station to UTC (USNO). The beginning of the first cycle of the first pulse (of Masters 9) of every tenth group was synchronized to the UTC second. In fact, the master transmitted a tenth, IPPS identifying pulse, preceeding by 1 ms the regular nine (the first of which was on the second). Synchronization to Loran was operationally quite simple

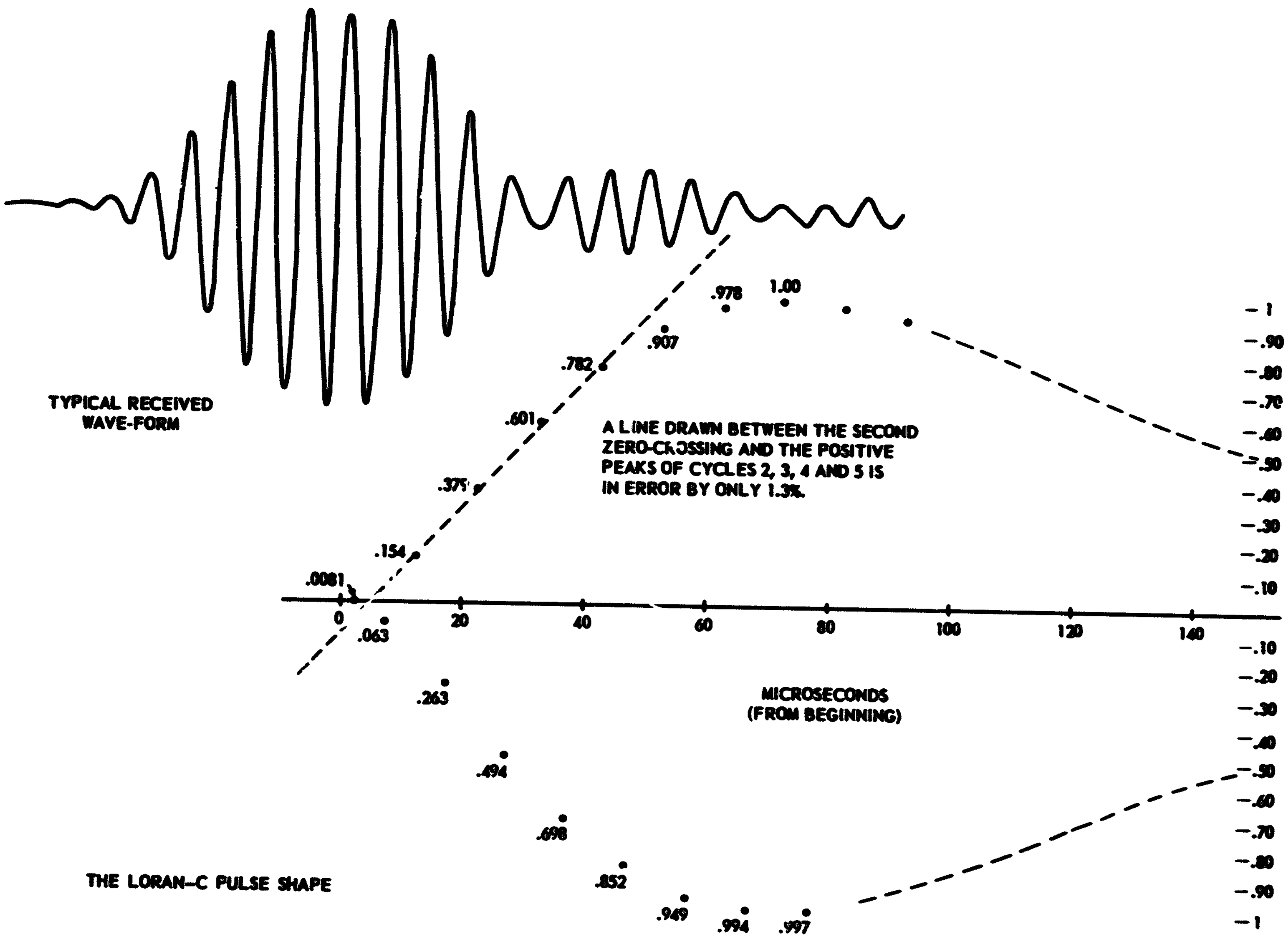


Figure 2. A Typical Loran-C Pulse

	MASTER	SLAVE-X	SLAVE-Y ETC.
FIRST REPETITION PERIOD	+ - - + + + + +	+ - + - + + - -	+ - + - + + - -
SECOND REPETITION PERIOD	+ + - - + - + -	+ + + + + - - +	+ + + + + - - +
THIRD REPETITION PERIOD	SAME AS FIRST REPETITION PERIOD		
FOURTH REPETITION PERIOD	SAME AS SECOND REPETITION PERIOD		

Figure 3. Phase Codes for Loran Transmitters

and the receivers required very little sophistication. The techniques employed were nearly identical to methods employed in HF (WWV) reception. The Loran-C pulse was viewed on an oscilloscope which was triggered by the local clock (to be synchronized). The delay between the trigger and the "on-time" Loran-C pulse (identified by the preceeding identifier) was measured. Subtracting the known propagation time from the measured delay yielded the clock error.

In 1968, however, the East Coast Chain repetition period (GRP) was changed to 99.3 milliseconds. At this rate, the Master's epoch (first pulse) occurs on the second only once every 19 minutes and 33 seconds. This makes the simple reception technique described above impractical in terms of operator time and the amount of transmitted signal actually used. Increased sophistication at the receiving end makes it possible to use all eight pulses and improve accuracy.

II. MODERN LORAN-C RECEPTION

A modern Loran-C timing receiver (see Figure 4) consists of basically five parts:

1. RF circuitry, which is little more than a low noise, high gain amplifier through which the received signal is increased in amplitude so it can be viewed on an oscilloscope. In addition, the phase of the received signal can be inverted to compensate for the phase-coding in the transmitted signal — in this way, all of the pulses are superimposed on the screen with same phase.

2. Pulse generating circuitry to provide oscilloscope triggering and phase-code gating to the RF circuitry.

3. A time-of-coincidence (TOC) circuit to relate the station time (1PPS) to the received Loran-C signal (GRP).

4. An electronic counter to display the data.

5. A loop antenna.

The heart of the pulse generating circuitry is a GRP pulse rate synthesizer which generates pulses at the same GRP rate as the stations in the Loran-C chain to be received. Note that when an oscilloscope is triggered at exactly this rate, the RF (amplified) signal (8 pulses from each station) would remain motionless on the display. The GRP generator has advance and retard circuitry to "slew" its output (the trigger) so as to move the desired signal to the proper position on the scope face. In actual operating conditions the first of the eight pulses would be slewed to the beginning of the trace so as to be coincident with the GRP generator.

The output of the GRP is also brought to a pulse-rate generator (PRR), where eight pulses spaced exactly 1 millisecond apart are generated after each GRP pulse. Thus if the GRP pulse is synchronized to the first of the 8 received (RF) pulses, then the PRR generator will be synchronized with all 8 pulses. The PRR generator can then be used to trigger the scope (at a fast sweep rate) and superimpose all 8 RF pulses on top of each other. This does not, in itself, improve the signal-to-noise ratio but makes viewing easier and the persistance of the CRT phosphor has an averaging quality. Since the transmitted pulses are phase-coded, the minus phase pulses must be inverted by phase-code generator as shown in Figure 4. Once the proper code has been chosen (either master or slave) and the proper code order is chosen (ABA or BAB because

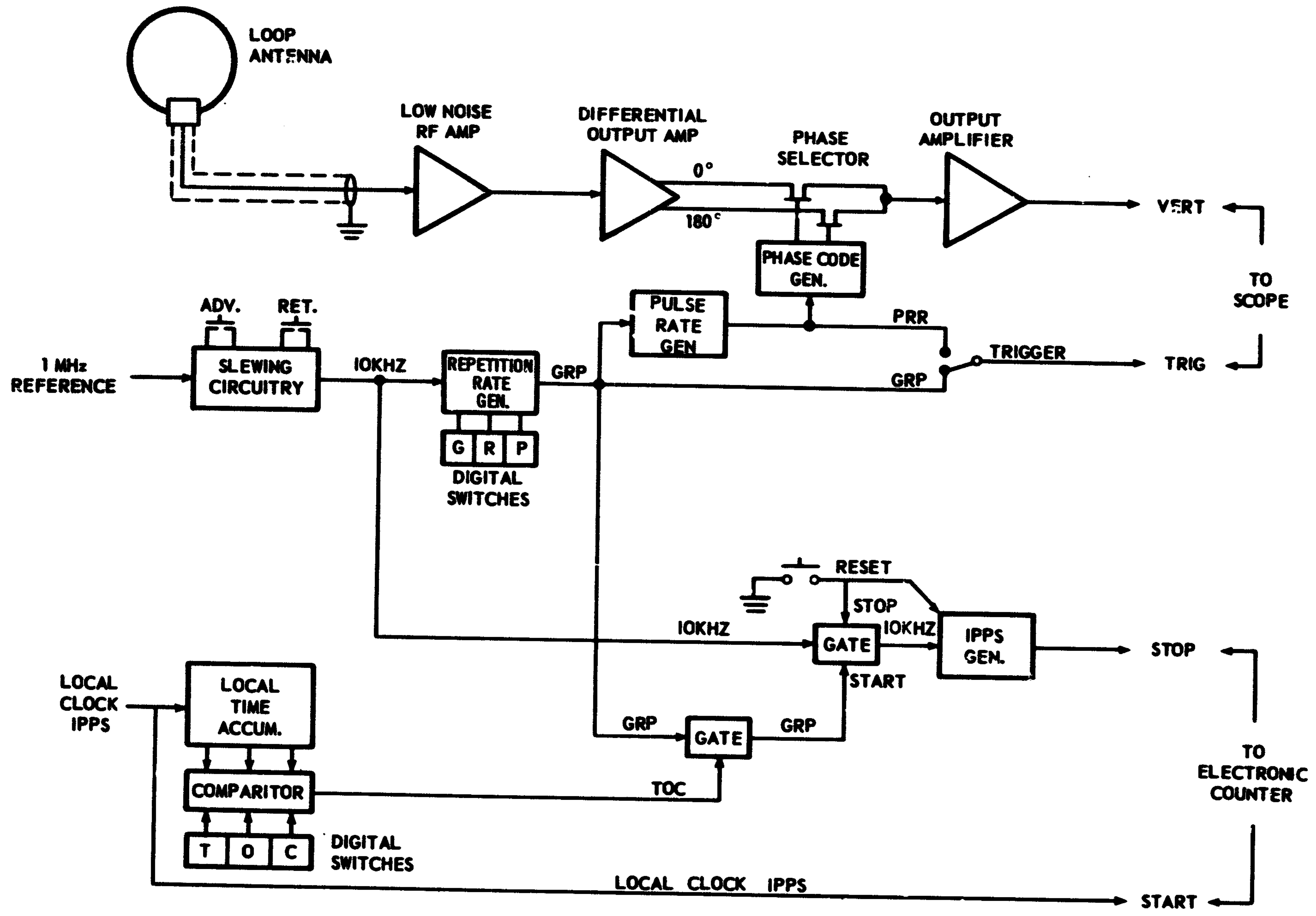


Figure 4. Simplified Block Diagram of a Loran-C Receiver

the code period is two GRP periods), all eight RF pulses will be superimposed, in phase, on the scope. (See Figure 5) Since the 100 KHz carrier frequency is well within the range of most CRT's, the individual cycles (10 microsecond period) can be seen. The GRP, PRR, and Phase code generators can now be slewed (simultaneously) in smaller amounts and to a greater resolution.

Once the GRP generator is synchronized to the beginning of the first pulse of the received station, the GRP can then be related to the station clock (1PPS) instead of the noisy received signal.

As noted before, for periods other than 100 ms, a GRP rate pulse and a 1PPS rate pulse can only coincide every few minutes. The time between coincidences is the least common multiple of the two periods (GRP and 1 second). For example, for a GRP of 99.3 milliseconds, one thousand intervals (of 99.3 ms) is equal to 993 seconds (which is 16 minutes and 33 seconds). Since no smaller multiple of 99.3 milliseconds is an integral number of seconds, this is the time between each "time of coincidence" (TOC). The United States Naval Observatory publishes tables giving the time (hour, minute, second) when each coincidence of the UTC second and the beginning of the first cycle, of the first pulse of the Master station will occur.

Once the GRP generator has been synchronized with the incoming signal, an electronic time-interval counter can be used to compare the GRP pulse with the local clock 1PPS. As just pointed out, however, the only valid counter

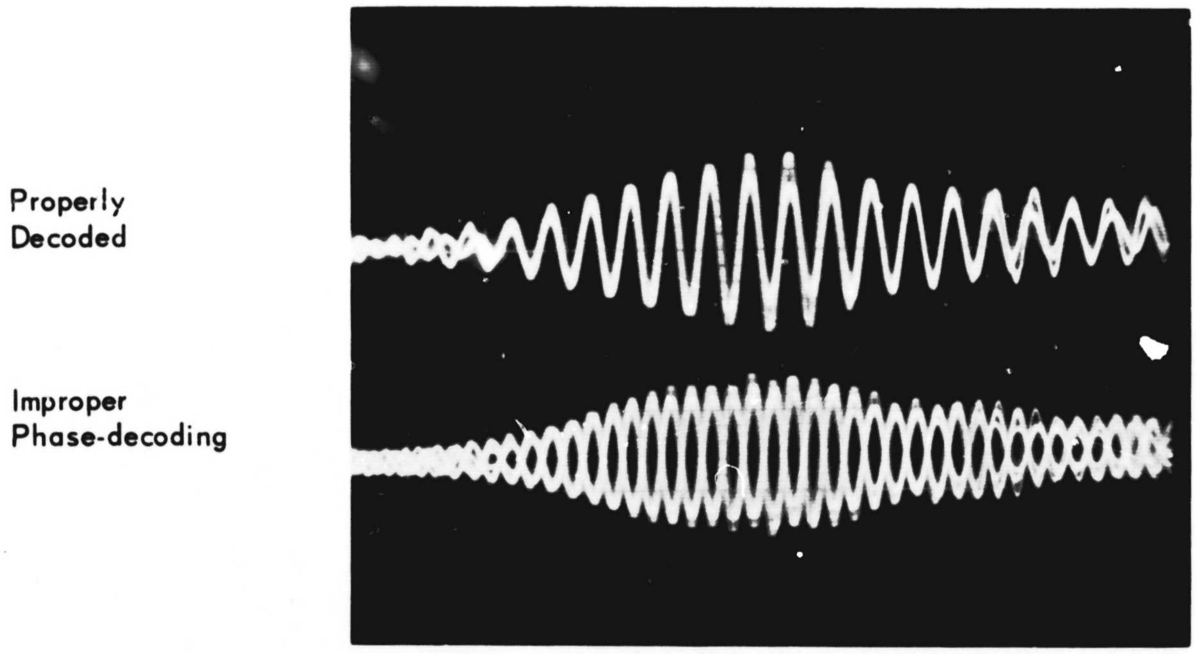


Figure 5. Phase Coded and Uncoded Pulses

reading will be that taken at the "TOC" second. Although this technique provides the needed data it is operationally cumbersome because valid data is obtained only every several minutes. A modern Loran-C timing receiver contains circuitry to make this comparison every second. As shown in Figure 4, the output of the advance/retard circuitry also goes to a 1 pulse per second generator. Note that the advance/retard circuit affects both the 1PPS generator and GRP/PRR/phase-code generators identically. Therefore, slewing the scope display to the right or left will retard or advance (respectively) the 1PPS generator an equal amount.

It is this 1PPS generator output that is used for the counter input instead of the GRP pulse rate. To be meaningful, however, the 1PPS generator must be exactly synchronized to the GRP generator at the actual TOC second. This synchronization is accomplished in the following manner:

The time (minutes and seconds) at which the next TOC will occur is inserted into digital switches whereupon the station time is continually compared with it. When the TOC arrives, a signal (on the second) from the comparitor allows (GATES) the <u>next</u> GRP to the 1PPS generator. The GRP then restarts the 1PPS so that at the TOC, the GRP and 1PPS generator are coincident. After the TOC second the GRP and 1PPS generators are again independent, but for the reasons explained previously, the two generators will not coincide again until the next TOC second. Note, this coincidence will occur even though the receiver is slewed because the phase of the 1PPS and GRP generators are equally affected by slewing. Therefore, the counter reading obtained by starting with the station clock and stopping with the 1PPS generator is equivalent to the difference (between the received Loran signal and the station clock) that will be obtained at the next TOC.

The receiving station, therefore, has the capability of measuring the time difference between the local clock and the Loran-C epochs. The local clock error can then be calculated by:

$$E = N - M - O$$
$$[(-) \text{ slow} \quad (+) \text{ fast}]$$

where:

E = the error of the local clock (1PPS) from the USNO master clock.
M = the measured (time interval counter) delay between the local clock and the received Loran-C pulse.
N = the nominal propagation delay from the Loran-C station to the receiver.

O = the published (USNO bulletin) error of the Loran-C chain (see appendix)

The parameter N discussed above can be obtained through either direct measurement by synchronizing the receiving station clock by some other means and recording the indicated delay, or by calculation. To be calculated, the exact co-ordinates of the receiving station must be known (to compute the propagation distance/delay), the emission delay of the particular Loran-C station to be used (if a slave) must be added, and the delay within the receiver must be measured and added.

III. SKY WAVE PROPAGATION

At 100 KHz signals propagate in two distinct modes; ground waves and sky waves. Ground wave signals follow a quasi-line-of-site path with signal strength falling off at roughly 24 db/1000 km. The propagation velocity of these signals is rather constant and stable allowing predictions of propagation delays to a couple microseconds. For timing purposes these signals have a usable range of approximately 1600 km.

Sky waves, on the otherhand, reflect off the ionosphere (and the ground) permitting reception at distances several times that of ground waves. Although the propagation velocity is constant the path geometry is quite variable. As can be seen in Figure 6, the number of hops the signal takes can be one of several, and in fact is the sum of the several possible hops (and the ground wave). By the geometry, it is obvious that the signals taking more hops require more time to propagate to the receiver. The additional delay is graphed in Figure 7.

The two curves are for daytime propagation (when the ionosphere has an effective height of approximately 70 km) and night-time propagation (effective height is about 90 km). These curves provide the additional distance (in microseconds) of travel per hop. As an example, consider 2-hop night reception at a distance of 3000 km. In addition to the great-circle propagation delay of approximately 10,007 microseconds, the signal would be delayed an additional 120 microseconds; at 1500 km per hop, there is a delay of 60 microseconds per hop. Similarly, at this distance the 3rd hop component would be delayed 210 micro-seconcs from the great circle path.

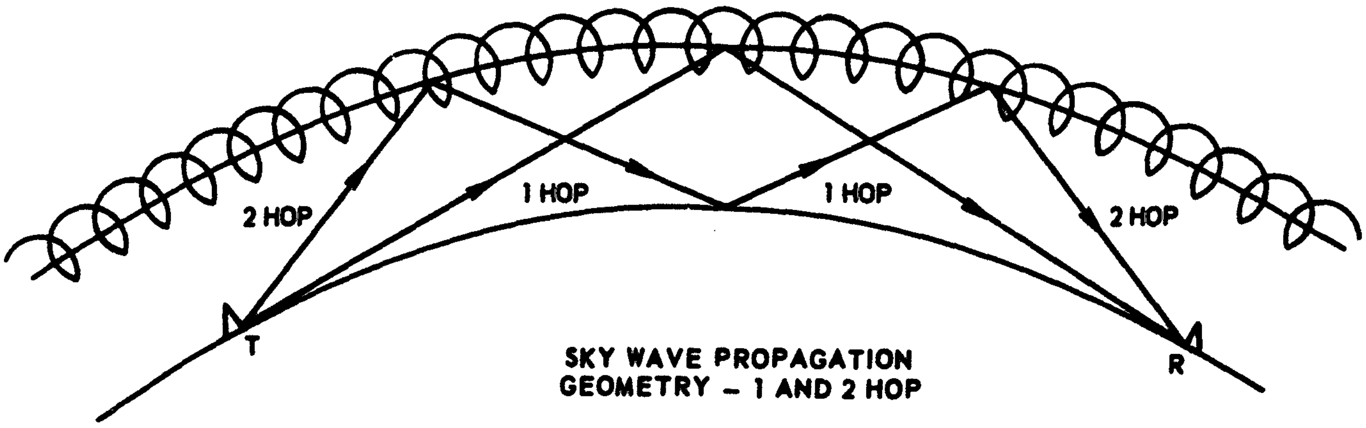


Figure 6. Sky Wave Propagation Geometry – 1 and 2 Hop

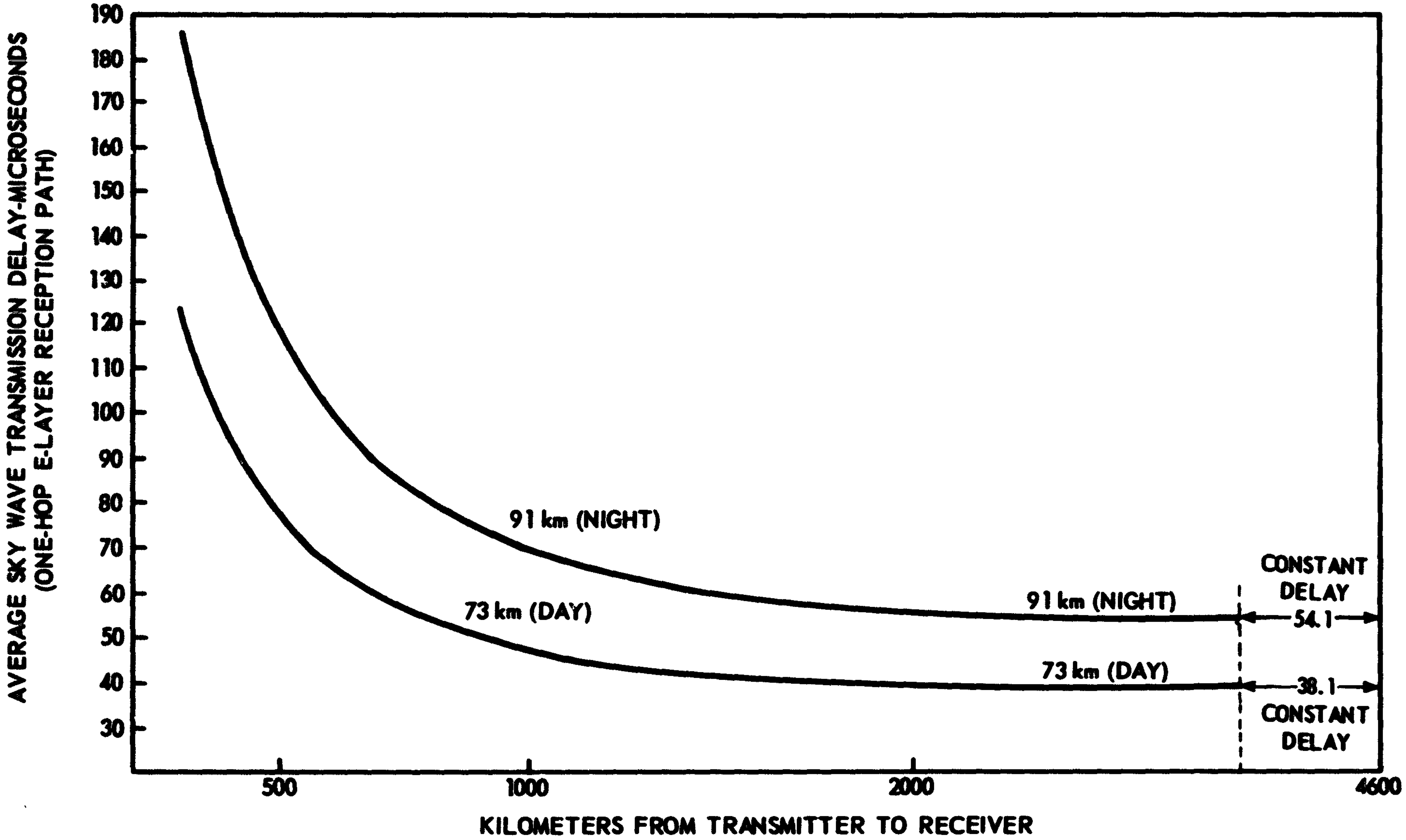


Figure 7. Skywave Delay Curves

As mentioned previously, the signal can actually have contributions from several hops, each delayed according to the additional path distance. Since this additional delay is not, in general, exactly a multiple of 10 microseconds (the period of 100 KHz), these multiple-hops do not arrive in-phase. Thus the envelopes of the incoming pulses do not exactly add (or subtract for that matter). This fact makes the acquisition of meaningful data more difficult. Various techniques for interpretting the received signal will be discussed in Section IV.

The lower ionospheric height in the day time, combined with higher ambient noise levels also at that time tends to limit the range of Loran skywaves compared to the range at night. Reception during the day time is usually limited to about 4000 km or about 2 hops. Whereas, at night time signals have been received at distance of as much as 15000 km with a timing capability of better than 25 microseconds. The range during either day or night is reduced significantly (by a factor of 2) due to scattering if the path is predominately over land rather than water.

Figure 8 shows the expected amplitude of several hops for propagation distances out to 18,000 km. One should note that a distance greater than approximately 2000 km no single hop predominates in signal strength over all others by more than 10 db. This fact has considerable impact from a timing point of view, because it is virtually certain that the received signal will be a conglomeration of two or more hops.

Of primary importance, therefore, is the development of techniques for consistantly identifying the same point (in time) in the received pulse envelope.

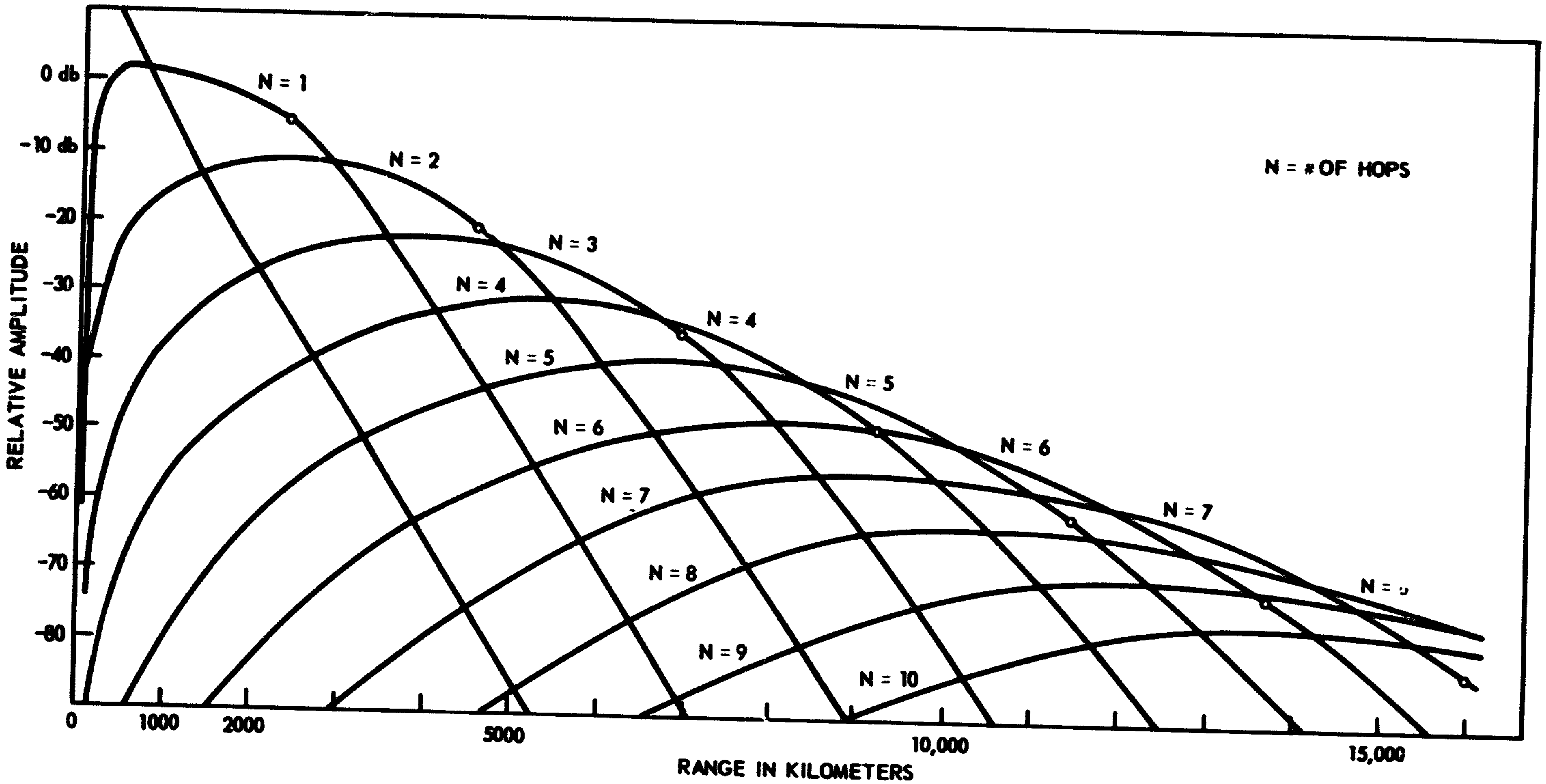


Figure 8. Relative Amplitude of Sky-Wave Signals

IV. CYCLE IDENTIFICATION OF SKY WAVE SIGNALS

Use of Loran-C for timing requires the identification of a point of reference or received pulse shape to which the station time can be compared. For ground-wave signals this can be the identification of the first cycle the peak (eighth) cycle, or any single or group of cycles in between. Sky-waves, as pointed out before, are a conglomeration of several hops which can distort the pulse envelope considerably.

A. High Amplitude Cycle

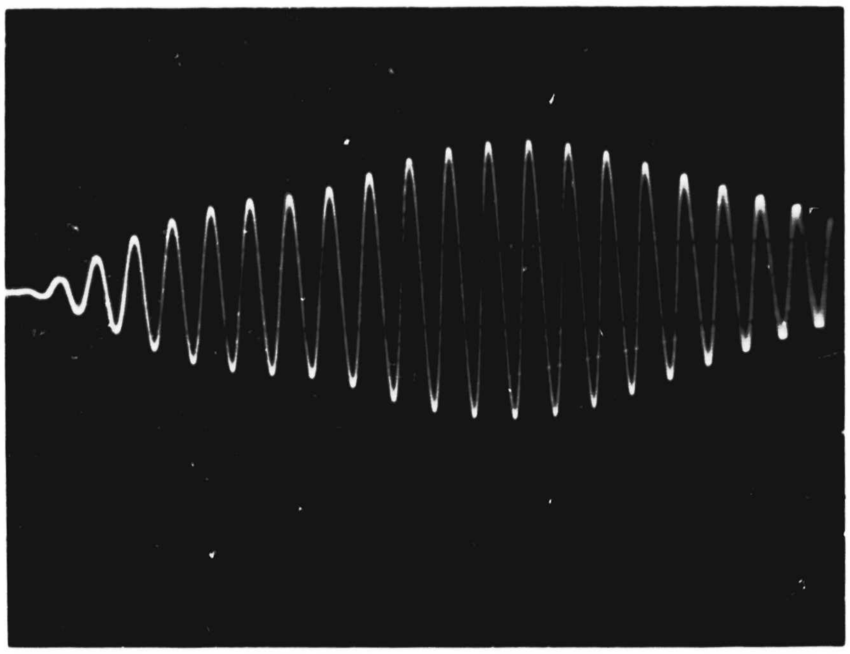
Consider the simplest method by which the highest amplitude cycle (nominally the eighth) is used as a reference. The eighth cycle of a nominal Loran-C pulse is approximately 3% higher in amplitude than the 7th or 9th. Therefore, only very small distortion due to other hops can be tolerated. Figure 8 shows that a first hop sky wave signal is stronger than the ground-wave at distances greater than about 70 km. Figure 7 shows, however, that this first hop will be delayed by greater than 72 us. Note the eighth peak is 72.5 microseconds after the beginning of the pulse for propagation distances up to about 900 km. Thus contamination of the eighth cycle (if it is actually the peak) will not occur at shorter distances.

Figure 9 shows the result of the addition of two Loran pulses of equal amplitude, one delayed by approximately 70 microseconds from the other. Note in trace (a), the peak pulse is five or six cycles away from the eighth, whereas in trace (b) the peak is approximately the eight cycle, however the peak is not well defined. In addition, the difference between two waveforms for only a two microsecond delay difference is also significant because it indicates that minor changes in ionospheric height could significantly change the indicated cycle.

In a similar manner, there are distances at which a first hop signal predominates over the ground-wave and the second hop signal is delayed sufficiently to make use of this technique, etc. At distances greater than 5000 km it is virtually certain that interhop distortion of the peak pulse will occur. This rules ou the use of predicted propagation values and exact cycle identification, however, night-to-night repeatability may be possible for some locations.

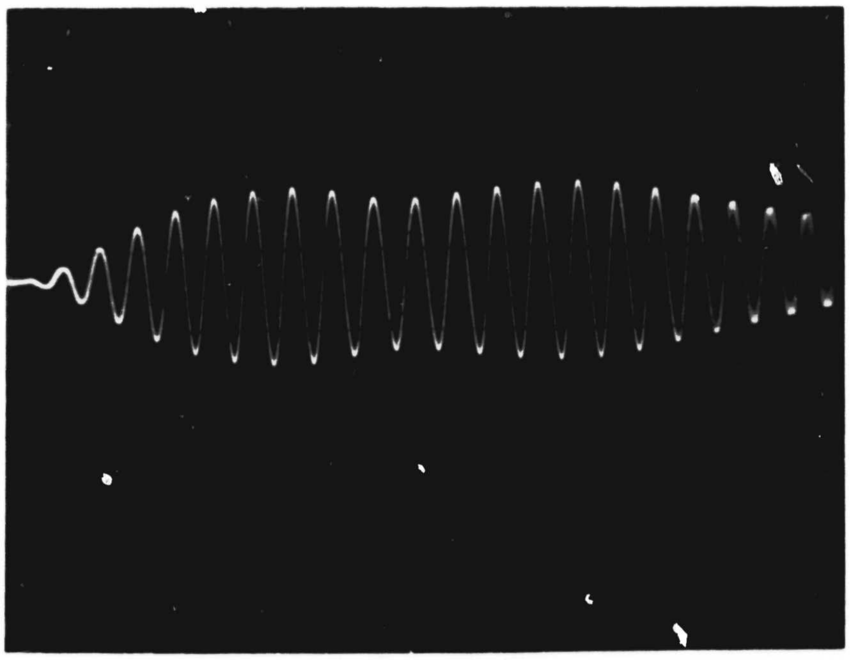
B. First Cycle Identification

Since a signal that takes more hops to arrive at a location also has a greater propagation time, it is obvious that the signal with the fewest number of hops will have the first few cycles undistorted. Specifically, for day-time propagation at least the first 3-1/2 cycles of one hop will be unaffected by the next,



Two signals of
equal amplitude
delayed 71 μ sec

Figure 9a



Two signals of
equal amplitude
delayed 73 μ sec

Figure 9b

Figure 9. Two Hops Separated By Approximately 70 Microseconds

and at night at least the first 5 cycles will be unaffected. For this reason there is considerable motivation for the development of techniques to establish cycle identification from the first few cycles of the earliest received hop. The envelope of transmitted pulse is carefully controlled to insure the reliability of such techniques.

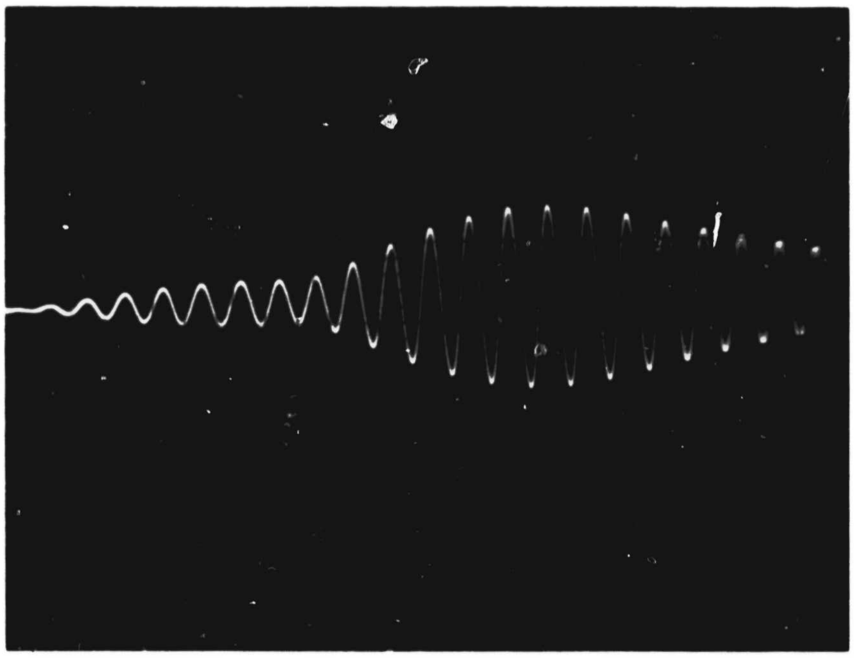
Figure 2 gives the relative amplitude (to the peak) of each half cycle of the transmitted Loran pulse. All cycle selector devices and techniques rely on the relative amplitude of the first few cycles. Most commercially built cycle selectors use two or more of the 3rd though 7th half-cycles so as to be useful for both day and night reception.

Since the first few cycles of the ground wave signal is unaffected by later hops, the maximum range at which the ground wave can be used is only limited to the received signal to noise ratio of ground wave. Referring to Figure 8, one can see that the signal strength of the ground wave and eventually every hop falls off at a rather rapid rate. In general there is one hop whose amplitude is within 10db of all succeeding hops but greater than 20db stronger than the next previous hop and therefore the first few cycles are not significantly distorted. Unfortunately, when signal-to-noise ratios become low a small amplitude early hop becomes difficult to analyze. Consider the example simulated in Figure 10. Traces (a) and (b) both represent two signals (hops) with the earlier pulse 12db down from the second. If one considers the received signal (a) in a high noise situation-it would be difficult to determine exactly where the first (or second) pulse begins. Such a situation for the received signal (b), is even more severe, since under an abnormally high noise conditions, a 70 microsecond error could easily be interpretted. It should be further pointed out that at ranges exceeding 4000 km a third hop could interfere with the second so that the peak cycle method described previously would be useless.

The previous discussion was intended to illustrate two important facts about Loran-C Skywave reception. First, that although the propagation time can be stable to a few microseconds, considerable change in pulse shape can and does still occur. Second, from a timing point of view, the most important part of the received wave-form is the first few cycles however weak they may be. Third, determination of the proper cycle of the received wave-form is important and requires considerable care even when an accuracy of only 50-100 microseconds is required.

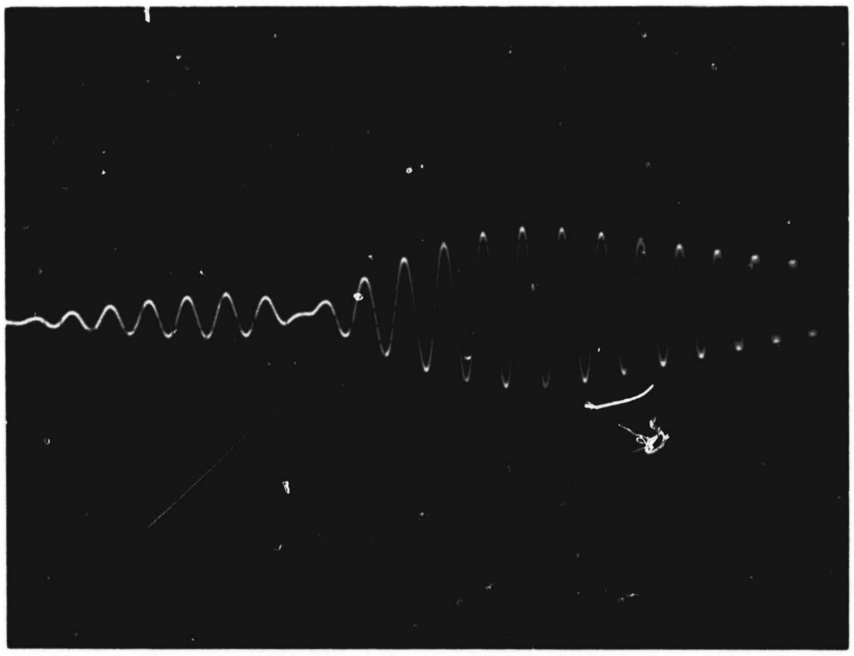
The following conclusions can be drawn and are recommended as a guide for the interpretation and identification of the proper cycle.

First hop 12 db
down from second
delay = 67 μ sec



(a)

First hop 12 db
down from second
delay = 65 μ sec



(b)

Figure 10. Two Sky-Wave Hops, First 12 db Down

1. The signal strengths, propagation time, and the actual hops received at any given location can be estimated however the exact wave-form received (or to be expected) must be determined at the receiving location under actual conditions. This is most easily accomplished by temporarily transporting a portable cesium clock to the site so that several days of data can be accurately collected and compared.

   During the period for which accurate time is available, such as with a portable clock, a complete profile of the Loran-C timing capability should be made. During this period a determination of the best hour of the night for reception, the best Loran-C station to be received, and the propagation time for each receivable station.

2. Best reception of Loran-C Sky-Waves is, of course, when both the transmitter and receiving station are in darkness as well as the great-circle path between them. Note that transmission over the North or South Pole during the local summer may not be possible. Of additional importance is ambient noise level which varies hourly as well as seasonally. Also for consideration may be the transmission schedule of LF and VLF radio stations which may interfere with reception.

   Strip chart recordings or pictures of each Loran station should be taken at intervals of one hour for as many days as possible. The recordings of the stations eventually selected, for all hours at which reception was possible, should be saved for future reference.

3. The best Loran-C station to be used should be the one for which cycle identification can be most confidently made. This includes, of course, high signal to noise ratio; however, more important to consider is the inter-hop envelope distortion of the first few cycles of the received signal. Since the propagation path does vary slightly during the night, the hourly recordings should be examined to detect changes in the envelope of the first 7-8 cycles. Such changes will indicate two or more signals changing phase. The station showing the least variation from hour to hour and day to day should be chosen as the primary station. With other, perhaps stronger, stations serving as a secondary or checking station.

4. Propagation times for all receivable Loran-C stations should be computed with the receiver delay, and transmitter coding delay not included. If at all possible, delay times for stations in more than one Loran-C chain should be obtained. Since, in general, the time synchronized Loran-C chains are only synchronized to ±15 microseconds, the readings taken initially, as well as operationally in the future, must be corrected after the fact by USNO published corrections.

V. RECEPTION UNDER HIGH NOISE CONDITIONS

The capability and usefulness of Loran-C for any purpose is very much a function of the received signal-to-noise ratio. There are three basic sources of noise at these frequencies: internal receiver noise, atmospheric and environmental noise, and locally generated RFI. Of the three types of noise, the least significant is that of receiver system noise. Although lack of antenna gain, high antenna temperature, R.F. transmission-line loss, and receiver front-end noise are primary considerations in most communications systems, such is not the case at 100 KHz. Consider, for example, the transmission-line loss for ordinary cable at 100 KHz. The loss of RG58/u, a low cost coaxial cable, is only .1db per thousand feet. High receiver sensitivity is afforded by low-noise, high gain amplifiers and very simple antennas. The R.F. amplifier stage in modern receivers typically has a sensitivity on the order 10 nanovolts.

Antennas used for VLF and Loran-C reception differ from more conventional types because they are designed to detect the magnetic field of the E-M RF wave rather than the electrical field. One might be reminded that a half-wave dipole at 100 KHz would be 1500 meters long (nearly a mile). As a result, the antenna is actually a coil, or loop, and is positioned so that the plane formed by the loop is parallel to the direction of the source, or transmitter. The amount of signal power at the receiving site is measured in watts per square meter. Similarly, the signal field is in terms of volts per meter — or more practically micro-volts per meter. Because of the extremely long wave length at this frequency high-gain directional antennas are not practical.

Modern receiving systems typically have a sensitivity of 1 microvolt/meter, whereas atmospheric noise is typically 10 to 100 microvolts/meter. The reception of signals with signal strengths in this region cannot be accomplished by refinements in receiver gain, or antenna system. Decreasing the receiver bandwidth increases the signal to noise, however, at the cost of distorting the pulse shape. A bandwidth of 30 KHz is considered necessary for proper cycle identification; further improvement requires more sophistication such as pulse averaging. One means of enhancing or improving the received signal is by the use of an oscilloscope camera. Using low CRT intensities and exposure times of up to 1-2 minutes provides considerable improvement while maintaining a good pulse shape. The enhancement comes about from the fact that the noise, which is generally gaussian-distributed, has an amplitude distribution which peaks at zero. Since the brightness of photograph image is somewhat proportional to the exposure time, it follows that a time exposure of a constant-intensity oscilloscope trace will be brightest at the average of the displayed wave-form. One should note, however, that resultant picture is not a display of the average pulse shape, merely brightest at the average. Never-the-less, time exposure photographs do provide a simple economical means of improvement, while also providing a permanent record of the data obtained.

This does, however, suggest that a true average of the received waveform would be a further improvement, which indeed it would. Such an average can be obtained by several methods — one such technique is by the use of a "synchronous filter" and is described in detail in Section VII.

A simpler, less expensive technique is the use of a "scan gate". With such a device, a small segment of the received wave form (about 1 microsecond) is sampled every repetition period. This voltage is filtered to provide an average for that segment. An average of the entire pulse is provided by moving this sampling window (in time) across the entire pulse, and plotting out the filtered potential on a strip-chart recorder. The actual improvement in signal to noise ratio can be computed for various filter time-constants. For gaussian noise, the improvement obtained is approximately the square root of number of times a particular point (in the waveform) is sampled in one RC time constant. This assumes, however, that the scanning rate is slow enough to permit the sampling of approximately that (RC time constant) number of times. A less heuristic development for a non-moving gate is given in Appendix A. Such a feature is extremely useful since an improvement in signal to noise actually occurs; the resolution of the wave form plotted out generally has better resolution than can be obtained from an oscilloscope screen, and the graphs obtained may be saved and used for comparison with future data. The only significant draw-back to this technique is due to the length of time required to graph out the pulse. To obtain a signal-to-noise ratio improvement of 10 db requires a scanning rate of about 1 microsecond per second — or abour 3 minutes for a 200 microsecond width presentation. Although in some cases the scan-rate could be slowed down to provide considerably more improvement, many locations experience noise which occurs in bursts. Burst noise distorts only the part of the presentation which is being graphed out during the burst. Such noise can seriously reduce the capability of the scan-gate technique by affecting the cycle-to-cycle amplitude relationship upon which cycle selection must rely.

One particularly common type of burst noise is that associated with thunderstorm activity. In areas within 30 degrees of the equator, and particularly in the summer when such storms are common, this type of noise is the dominating source.

Since the bursts of radio interference resulting from a lightning stroke propagate so well at 100 KHz, one storm can increase the noise level at a receiving site thousands of kilometers away. The impulse nature of such noise seriously effects most receiving techniques, particularly if allowed to pass into the receivers filter circuitry where "ringing" tends to propagate its effects. For this reason, modern receivers are equipped with either noise blanking or noise limiting circuits which detect noise bursts and cut-out, or limit, the signal passed on through the receiver for the duration of the burst. Careful adjustment of such circuits can considerably improve the operation of scan-gate circuits or synchronous filters.

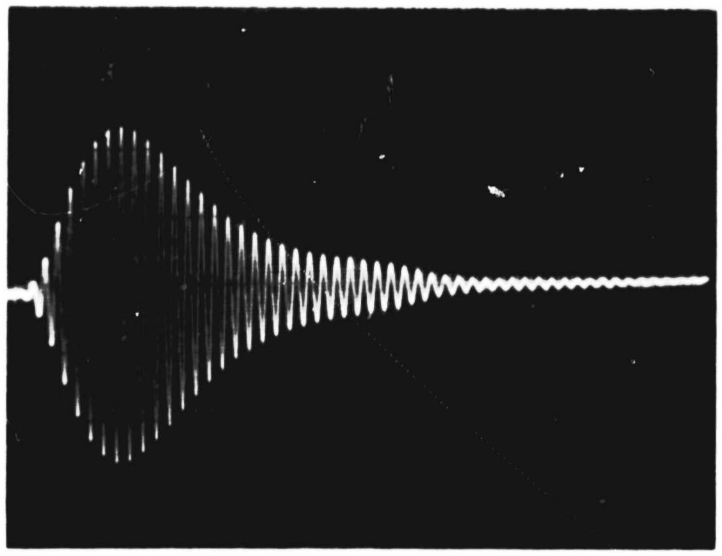
A common and often very fustrating source of noise is RFI generated in the vicinity of the receiving system, or extremely powerful low frequency radio stations, such interference is characterized by being spectrally rather pure and within the receiver bandwidth. Of considerable problem is that type interference generated by other timing equipment which is often rich in 100 KHz.

The most useful tool for eliminating coherent RFI, not at exactly 100 KHz, is the notch filter. The notch filter provides a means of nulling out a 2-3 KHz segment of the receiver band pass without significantly attenuating other frequencies. Tuning of notch filters can be difficult, particularly when more than one interfering signal is present or if the 100 KHz Loran signal is not discernable and therefore not usable as a basis of comparison. One highly recommended approach is the use of a spectrum analyzer such as a Tektronix 1L5. Connecting such a device to the output of the receiver will indicate the frequency and relative amplitude of the interfering signals.

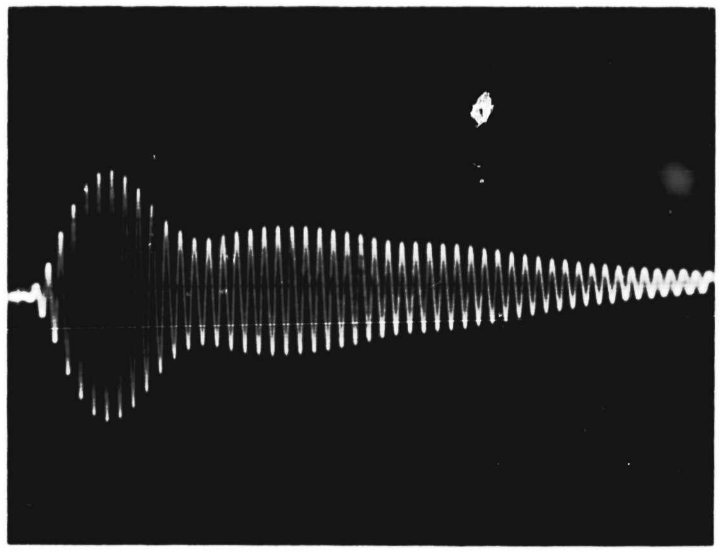
The spectrum analyzer will allow you to properly tune and evaluate the performance of the notch filter. One important fact becomes apparent in many situations; although the normal receiver bandwidth is 30-35 KHz, interference from signals ±40 KHz is quite common. Receiver bandwidths only represent the frequency extremes for which signals are suppressed 3db. For example, a 3-pole Butterworth filter with a 3db bandwidth of 30 KHz (±15KHz) will suppress frequencies at ±30 KHz from the nominal center frequency by 18db; the 30db point is ±45 KHz. Considerable use of this spectrum is being made, and the presence of signals 30db or more stronger than the Loran-C signals is common.

Because Loran-C is an AM pulsed system, the transmitted signal's spectrum covers a range of frequencies instead of just 100 KHz. In fact, nearly all the information required for cycle selection (the first few cycles) lies just below 100 KHz. For this reason, the tuning of notch filters in the vicinity of 100 KHz can distort the Loran-C pulse, but not completely null it out. How much distortion occurs depends considerably on the characteristics of the notch filter. Figure 11 shows what happens to a Loran (simulator) pulse when the notch filter is tuned to exactly 100 KHz. For the case of a -3db notch bandwidth of 1KC, the shape of the pulse is affected slightly, however, the first few cycles

Normal
Simulator
Output



Notch tuned
to 100 kHz
B.W. = 1.5 kHz



B.W. = 15 kHz

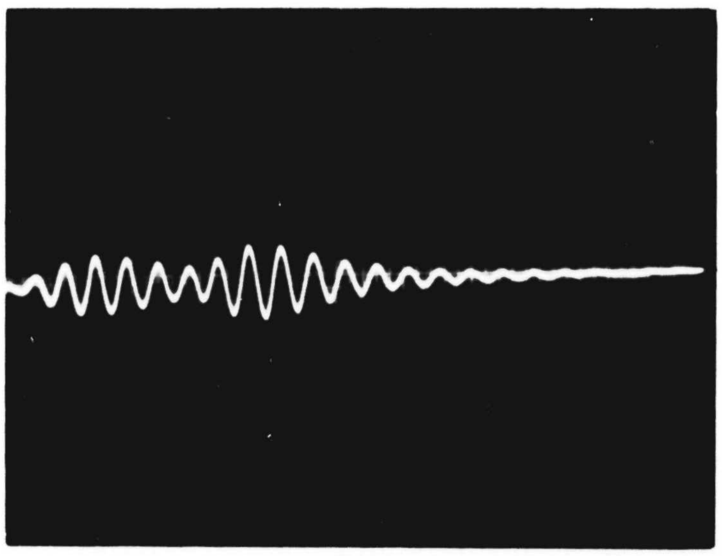


Figure 11. Distortion From A Notch Filter Tuned To 100 kHz

are not significantly distorted. With a notch filter with a (-3db) bandwidth of 15 KHz, however, severe pulse attenuation is obtained also severe phase shifting occurs when the filter is adjusted in the vicinity (±10 KHz) of 100 KHz. Thus the adjustment of such notch filters is important and an extremely narrow notch is desirable if tuning in the vicinity of 100 KHz is necessary.

Notch filters are not a cure-all for locally generated RFI problems, and there are several other alternatives:

1. Since the loop antenna used for Loran-C reception is directional (cosine-squared pattern) it can be used to null out the noise. Of course the amplitude of the Loran-C signal will be compromised using such a technique, and in addition a phase shift to the received signal will occur (±5 microseconds).

2. If the rotation of the antenna has no or little effect on the amplitude or RFI, it may mean that the interference is being picked up by the antenna feed-line. This can be checked by running a separate cable from the receiver to the antenna which avoids regular cable ducts, patch panels, and under-the-floor wiring. Often such a special cable run, will provide sufficient improvement.

3. If special cable runs are not practical or possible, the use of special co-axial cable maybe necessary. A double shielded coaxial cable such as RG223 has been shown to provide somewhat better isolation than RG58.

   An extremely noisy environment may necessitate moving the equipment to a quieter less noisy location or building.

Since all timing systems operate in decade frequencies, 100 KHz signals are always present. Many systems, such as the Astrodata 6600 systems, use 100 KPPS to clock the synchronous dividers so that considerable 100 KHz noise must be expected. Also, 100 KHz is distributed from the timing system to many pieces of equipment and patch-panels in the tracking stations. These cables can become a source of FRI particularly if they are not properly terminated, which is often the case for unused patch panels.

An indication of coherent 100 KHz interference is an increase in noise amplitude when the receiver bandwidth is reduced.

In addition to the solutions mentioned previously, the following may improve reception particularly if such coherent 100 KHz RFI is encountered:

5. Insure that all cables carrying 100 KHz signals from the timing system are properly terminated. In the case of patch paneis, self-terminating sockets are available which will terminate these cables when not being used.

6. If the Loran-C receiver is located within or near the timing, system, it may be necessary to move it to another equipment rack.

7. The use of "Balanced" phase decoding and a scan gate or synchronous filter.

"Balanced" phase decoding takes advantage of the inherent phase coding of the Loran-C signals. If an equal number of positive and negative phase pulses are averaged (corrected for the phase coding of course) a coherent 100 KHz signal will cancel completely. Unfortunately such balance phase decoding does not improve oscilloscope presentations since both phases of the interference are displayed. The use of a scan-gate, or synchronous filter with averaging times sufficiently long to include an equal number of each phase will produce the desired results. Note that most receivers with balanced phase decoding capability still display all eight pulses although internally some are omitted.

The codes are often used for such balanced phase decoding and are shown below

Code	MASTER	SLAVE
Normal	+ - - + + + + + + + - - + - + -	+ - + - + + - - + + + + + - - +
Group	⁝ - ⁝ + ⁝ + ⁝ + ⁝ + ⁝ - ⁝ - ⁝ -	⁝ - ⁝ - ⁝ + ⁝ - ⁝ + ⁝ + ⁝ - ⁝ +
Frame	+ - - + ⁝ ⁝ ⁝ ⁝ + + - - + - + -	+ - + - + + - - ⁝ ⁝ ⁝ ⁝ + - - +

Figure 12. Balanced Phase Coding

The "Group" code, which takes every other pulse, omits four out of every eight pulses and achieves an equal number of plus or minus phases after every 16 pulses. The "Frame" code obtains an even number every 4 pulses. Neither code is optimum in terms of using all of the available 16 pulses. These codes are easily generated and provide some improvement for interference at other frequencies. The better of the two for each situation must be found experimentally.

VI. NON-SYNCHRONIZED LORAN-C CHAINS

Several Loran-C chains at the present time are not synchrcnized to UTC, but are on frequency — being controlled by Cesium beam frequency standards. The signals from such chains may be used for frequency synchronization to accuracies up to parts in 10^{-12} depending on propagation distance. The use of Loran-C for frequency synchronization is, in principle, identical to the techniques employed for standard VLF reception. That is, the phase of the received signal may be compared to the local oscillator and this information is used to correct the oscillator; or, the receiver may be phase-locked to the received signal and outputs coherent to the received signal can be distributed.

In some locations Loran-C offers several advantages over ordinary VLF. Since Loran-C is a pulsed system with an accurately controlled envelope, the same cycle of the 100 KHz reference carrier can be reliably acquired so that Loran-C has a phase ambiguity of several tens of milliseconds the GRP. VLF, on the otherhand, has an ambiguity of tens of microseconds (50 microseconds at 20 KHz) and can cause a loss of correlation if the local timing system jumps in time, or otherwise temporarily fails. The Loran-C receiver does not generally need back-up battery power and temporary down time can usually be tolerated. Secondly, Loran-C ground-wave signals are more stable than VLF signals, and they experience almost no duirnal phase shift from day to night.

Non-synchronized chains may be used for timing if the transmitted epochs can be related to UTC by some independent receiving station (just as the USNO monitors time-synchronized Loran-C chains). The independent "calibrating" station must achieve time synchronization by some other means-perhaps another Loran-C chain as diagramed in Figure 13.

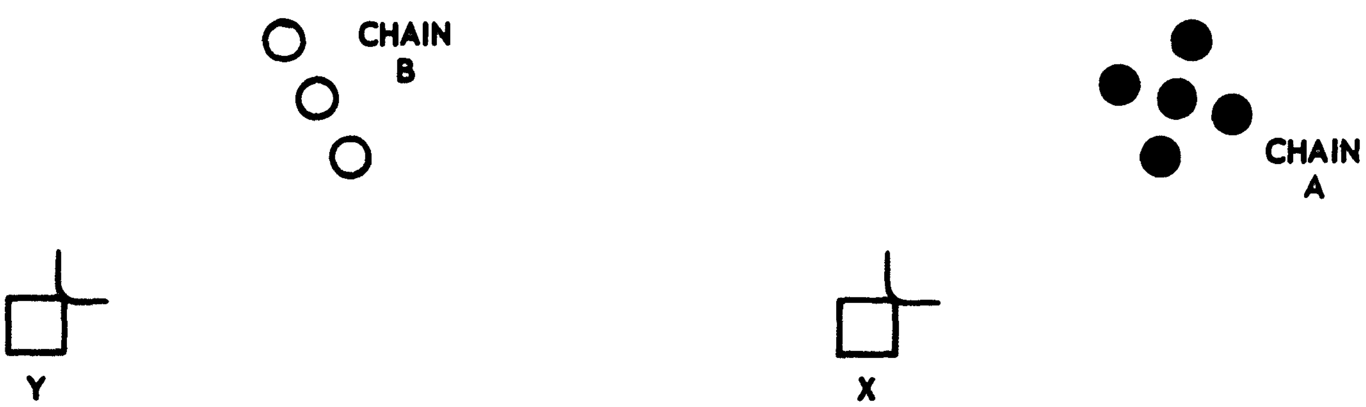


Figure 13. Time Transfer Via Two Loran-C Chains

As shown a clock at location Y requires synchronization but cannot receive signals from a time synchronized Loran-C chain — it can, however, receive epochs from a nonsynchronized Loran-C chain (B). It happens, also, that another friendly Loran-C user at location X can receive signals from both the synchronized Loran-C chain A and the unsynchronized Loran-C chain B. To synchronize Clock Y, it is only necessary to assume that chain B is approximately time synchronized and have X measure the synchronization "error" of Loran-C chain B. This information is passed on to Y who corrects the Loran data received via chain B to obtain his own clock error. To perform this type of time transfer it is necessary to generate a TOC table for chain B — which i a function its GRP and an arbitrarily agreed-upon initial time of coincidence. Ideally, station X should monitor chains A and B at the same time station Y monitors chain B so that oscillator offsets or time jumps at clock X or chain E will not affect the results.

Calculation of Y's clock error is as follows:

If chain B were synchronized

$$E_y = N_{BY} - M_{BY} - O_B$$

However, since chain B is not synchronized by USNO, O_B must be determine via X. Thus:

$$O_B = N_{BX} - M_{BX} - E_X$$

If the clock error at station X were zero:

$$E_Y = N_{BY} - M_{BX} + M_{BX}$$

and Y could determine his clock error. However, if clock X were not necessarily on time, but used Loran-C for synchronization, the following would apply:

$$E_X = N_{BY} - M_{BY} - N_{BY} + M_{BX} - E_X$$

Since X used the time synchronized chain A,

$$E_Y = N_{AX} - M_{AX} - O_A$$

So,

$$E_X = N_{BY-M_{BY}} - N_{BX} + M_{BX} - N_{A_X} + M_{AX} + O_A$$

By re-arranging,

$$E_Y = (N_{BY} - N_{BX} - N_{AX}) - (M_{BY} - M_{BX} - M_{AX}) + O_A$$

Since M_{BY}, M_{BX}, and M_{AX} are constants their sum is constant. Therefore, we can define.

$$M_Y = M_{BY} - M_{BX} - M_{AX}$$

Thus we get the expression

$$E_Y = N_{BY} - \left(N_{B_X} + N_{AX}\right) - M_Y + O_A$$

Which is probably the most useful since it does not require that X actually be synchronized or perform any computation. It is only necessary that X relay the raw data obtained from both chains to station Y.

Note, also, that M_Y can be obtained by an on site calibration (portable clock for example) by forcing $E_X = 0$ so that

$$M_Y' = N_{BY} - (N_{BX} + N_{AX}) + O_A$$

VII. THE SYNCHRONOUS FILTER

The capability of Loran-C is almost completely determined by the signal strength at the receiving location. Even problems in cycle identification can be solved if a sufficiently high signal-to-noise ratio is available. As explained previously, reducing the viewing bandwidth below 30 KHz by conventional filtering distorts the pulse envelope. Since the propagation path is stable, pulse averaging reduces the zero-mean noise. An average of N such signals should reduce the standard deviation of the noise by $1/\sqrt{N}$.

Since the Loran-C pulse is an analog wave form, of some complexity, the storage and algebraic averaging of such a received signal is rather difficult in its received form. For this reason, in a practical averaging device, the received viewing window in divided up into many equally spaced intervals of τ microseconds each. The received signal is sampled (integrated) during each interval and the value is stored separately for each interval. The values obtained for each interval from N received pulses can then be averaged. From the M averaged values, an average received wave-form can be constructed.

From the above over-simplified description several very basic criterion for such a system are apparent. First, the sampling rate $(1/\tau)$ must be greater than twice the frequency of the signal to be averaged — otherwise phase-correlation with the received signal would be lost. Actually the Sampling Theorm says this requirement is sufficient to prevent lose of any information. Second, the sample obtained for each interval from all M pulses must be stored individually and averaged after they have all been received, or the sample for each interval must be combined with all previous values in that interval in such a way that after the M'th sample, the result is the average. The later technique would be preferred since only one storage device per interval would be required. The type of storage device used can be either analog or digital in nature, and implementation of both have been made. If digital storage is used, the device must have an analog-to-digital converter (ADC) of sufficient speed and precision. The ADC must obtain the digital value of amplitude in the time so that only one ADC would be necessary. To do otherwise would be impractical in terms of cost as well as, most-likely, interval-to-interval linearity. The precision of such a DAC must be such that the "Quantization noise" not significantly contribute the result.

The simplest analog storage device is that of a capacitor, which provides probably the least complicated implementation of such a signal averaging device (synchronous filter). Figure 14 below shows a simplified diagram of such a synchronous filter and is only used as an illustration. The received signal from a standard Loran-C receiver is amplified, fed through a resistance R, to

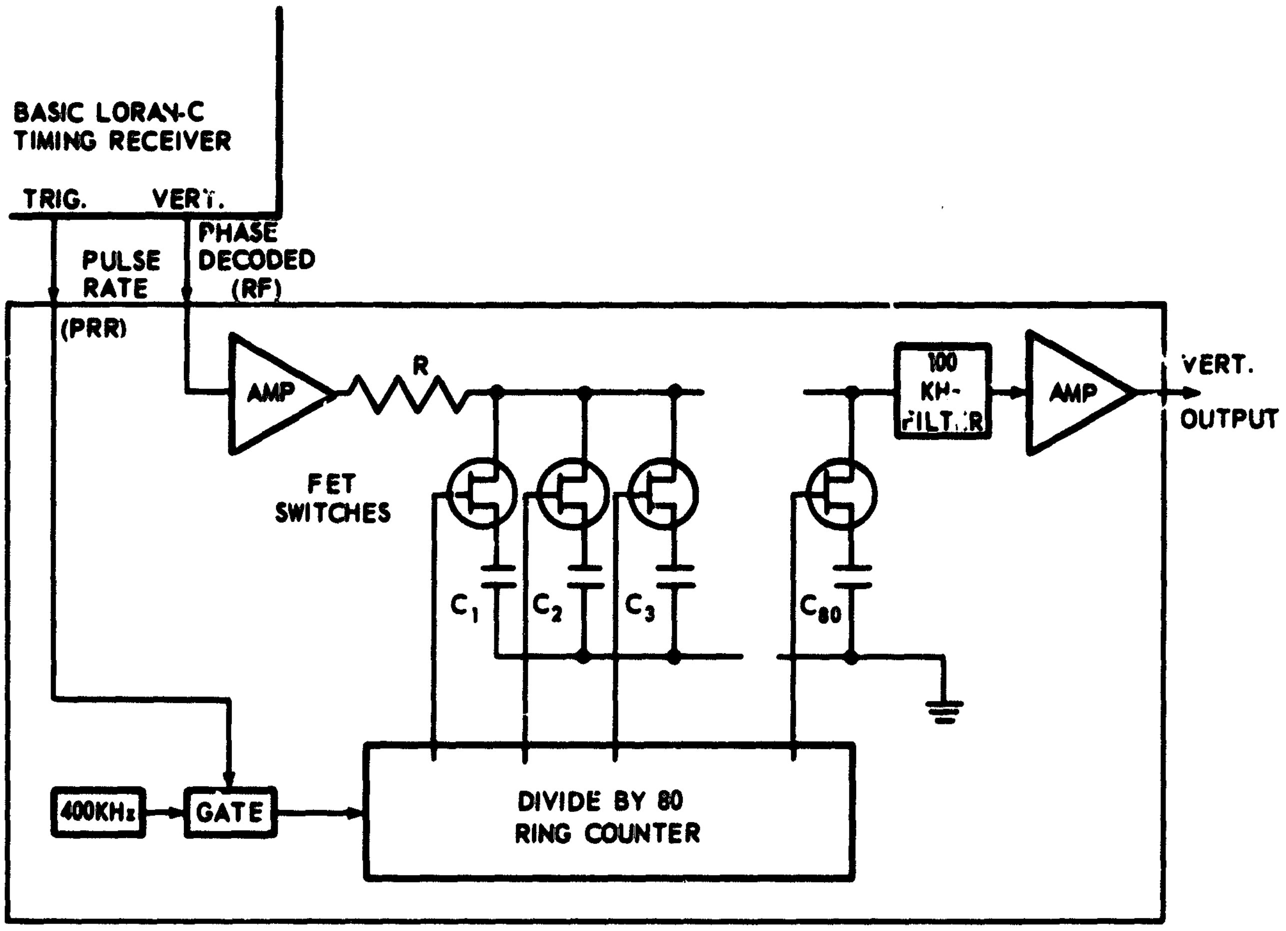


Figure 14. Simplified Diagram of a Synchronous Filter

a bank of Field· transistor (FET) switches. Only one FET switch is open at a time and is rmined by a ring counter. The ring counter begins counting the 400 KHz sigr after each PRR pulse supplied by the receiver. Each count of the ring count.., lasting nominally 2.5 usec (one period of 400 KHz), opens one FET switch, which in turn allows one capacitor to be charged by the received signal during that interval. Note that for the 100 KHz Loran signal there will be 4 samples per cycle, and for the 80 interval example (commonly used) 20 cycles of a Loran pulse may be averaged. The average output (the voltage across the capacitor) may be read simultaneously by sampling the present voltage on each capacitor, filtering to remove step jumps in the output, and displaying it on an oscilloscope CRT.

VIII. OPERATIONAL CONSIDERATION FOR LORAN-C TIMING

The United States Coast Guard, in conjunction with the United States Naval Observatory controls Loran-C transmission for timing purposes. At present the timing capability of Loran-C chain falls into one of three possible catagories.

1. Time synchronized and phase controlled Loran-C chains are maintained within ±15 microseconds of UTC. The master stations of such chains are equipped with sufficient redundancy to maintain this accuracy even after equipment failures. The chains which are presently in this catagory are:

   a) Norwegian Sea
   b) East Coast U.S.A.
   c) Central Pacific (Hawaii)
   d) Northwest Pacific

   In addition, these stations transmit a 1PPS "tick" consisting of one standard Loran pulse with the beginning on the second.

2. Time monitored Loran-C chains are those for which the USNO is able to measure and publish the time in the Series 4 bulletins. These chains are not necessarily maintained within ±15 microseconds and could experience jumps in time due to equipment failure. Stations presently in this category are:

   a) Mediterranean
   b) North Atlantic

   These stations do not transmit a 1PPS time tick.

3. Unsynchronized Loran-C chains are not related to UTC and therefore time errors are not published. Their transmissions are controlled by cesium-beam frequency standards and should exhibit good frequency stability, however time jumps must be anticipated. Such chains are:

   a) North Pacific (Alaska)
   b) Southeast Asia

Since equipment failures and other operational difficulties are possible in a Loran-C chain, the Master station will intermittently omit the transmission of its 9th identifier pulse when the chain is unusable for navigation and timing. Therefore the master stations transmissions should be checked, if possible, for such a condition. Normally the Master identifier is blinked in Morse code — the character R (. - .) followed by one, two, three, or four, indicating respectively leg X, Y Z or W is unusable. Slave stations, similarly blink their first two pulses (about .25 seconds on — 3.75 seconds off). Another indication that a particular station may be unusable for is the transmission of only one phase of the phase code, with the opposite phase pulses omitted. It should be noted that under this condition, phase-tracking type receivers may often remain phase-locked although at a reduced signal to noise ratio. Thus during each time check, the operator should view the received signal (photograph if necessary) on an oscilloscope at the chain repetition rate. (GRP)

Anticipated changes in the operation of and emissions from Loran-C stations are published in advance in the USNO "Time Service Announcement, Series 3". The status, coordinates and emission delays of Loran-C stations are given in "Time Service Announcement, Series 9.

The clock error of all time synchronized or monitored Loran-C chains is contained in USNO daily TWX messages and is also summarized weekly in the USNO "Daily Phase Values Series 4" bulletins. The values published refer to the Master clock at USNO and reflect the error indicated if the chain's transmissio· · ·ere received in Washington, D. C. That is, the published numbers are positiv. (+) if the chain is slow, and negative (-) if the chain is fast. Hence the equation presented previously for determining clock error by Loran-C.

$$E = M - N - O$$

The improvement obtained from a synchronous filter as described in Section VII can be calculated by considering the voltage across just one of the M (80) capacitors. During each interval (τ) the voltage V (t) supplied by the receiver is assumed to be:

$$V(t) = S + X_i$$

Where S is the Loran-C signal and X is the noise during the ith sample. It is further assumed that X_i are independent, identically distributed, zero mean, gaussian random variables. After the first sample the voltage across the capacitor would be:

$$V_0 = (S + X)\,(1 - e^{-\tau/RC})$$

For simplicity, consider an interval where the average signal is zero so that the only contribution is that of the noise. Then,

$$V_0 = X_0\,(1 - e^{-\tau/RC})$$

After the second sample, the voltage across the capacitor is:

$$V_1 = (X_1 - V_0)\,(1 - e^{-\tau/RC}) + V_0$$

or,

$$V_1 = X_1\,(1 - e^{-\ /RC}) + V_0\,e^{-\tau/RC}$$

This final equation established a recursion relation for all future samples.

$$V_N = \sum_{i=0}^{N-1} Xi\,(1 - e^{-\tau/RC}) \cdot e^{-i\tau/RC}$$

Since the Xi are random variables, V_N cannot be explicity determined, however some facts about its distribution are known. Since Xi are, independently gaussian distributed, V_N is also gaussian. Since the variance of the sum of gaussian random variables is equal to the sum of the variances.

So,

$$\mathrm{Var}\ (V_N) = \mathrm{Var} \sum_{i=0}^{N-1} Xi\ (1 - e^{-\tau/RC}) \cdot e^{-i\tau/RC}$$

$$= \sum_{i=0}^{N-1} \mathrm{Var}\ Xi \cdot (1 - e^{-\tau/RC}) \cdot e^{-i\tau/RC}$$

Since all Xi have zero mean and are identically distributed

$$\mathrm{Var}\ (V_N) = (1 - e^{-\tau/RC})^2\ \mathrm{Var}\ (Xi) \sum_{i=0}^{N-1} e^{-2i\tau/RC}$$

or,

$$= (1 - e^{-\tau/RC})^2\ \mathrm{Var}\ (X) \sum_{i=0}^{N-1} (e^{-2\tau/RC})^i$$

The final form above can be identified as a geometric series which will have the value:

$$\mathrm{Var}\ (V_N) = \frac{\mathrm{Var}\ (X)\ (1 - e^{-\tau/RC})^2\ [1 - e^{-2N\tau/RC}]}{(1 - e^{-2\tau/RC})}$$

The signal to noise ratio can now be calculated by dividing the above expression into the variance of the input signal with no noise after N samples. The variance of the noiseless signal can be written as:

$$\mathrm{Var}\ (S_N) = (1 - e^{-N\tau/RC})^2 \cdot \mathrm{Var}\ (S_N)$$

The signal to noise ratio of the output Var (S_N)/Var (V_N) can now be calculated for a given signal and noise level. Of more significance, however, is the improvement provided by the device. The improvement can be written as:

$$I_{(N)} = \frac{\text{Var }(S_N)/\text{Var }(V_N)}{\text{Var }(S)/\text{Var }(X)} = \frac{(1 - e^{-N\tau/RC})^2\,(1 - e^{-2\tau/RC})}{(1 - e^{-\tau/RC})\,(1 - e^{-2N\tau/RC})}$$

The improvement (I(N)) is an increasing function (see Figure 14) of N; this is reasonable since the longer the signal is averaged, the more improvement one would expect.

As N increases, the function asymptoticably approaches the value:

$$I(\infty) = \frac{(1 - e^{-\tau/RC})^2}{(1 - e^{-2\tau/RC})}$$

Since an infinite averaging time is impractical, the question arises of how long one must want to achieve a desired degree of accuracy. After N equal to RC/τ samples, I(N) is almost within 3db of $I(\infty)$. For a Loran-C chain repetition rate of 100 ms, an RC/τ samples occur after 500 RC seconds; which is referred to as the receiver time constant (RTC).

The improvement for various RTC's is given in Table 2.

Table 2

RTC	R.C.	I(∞) (db)
5	.001	29
50	.01	39
500	.1	49
1000	.2	54

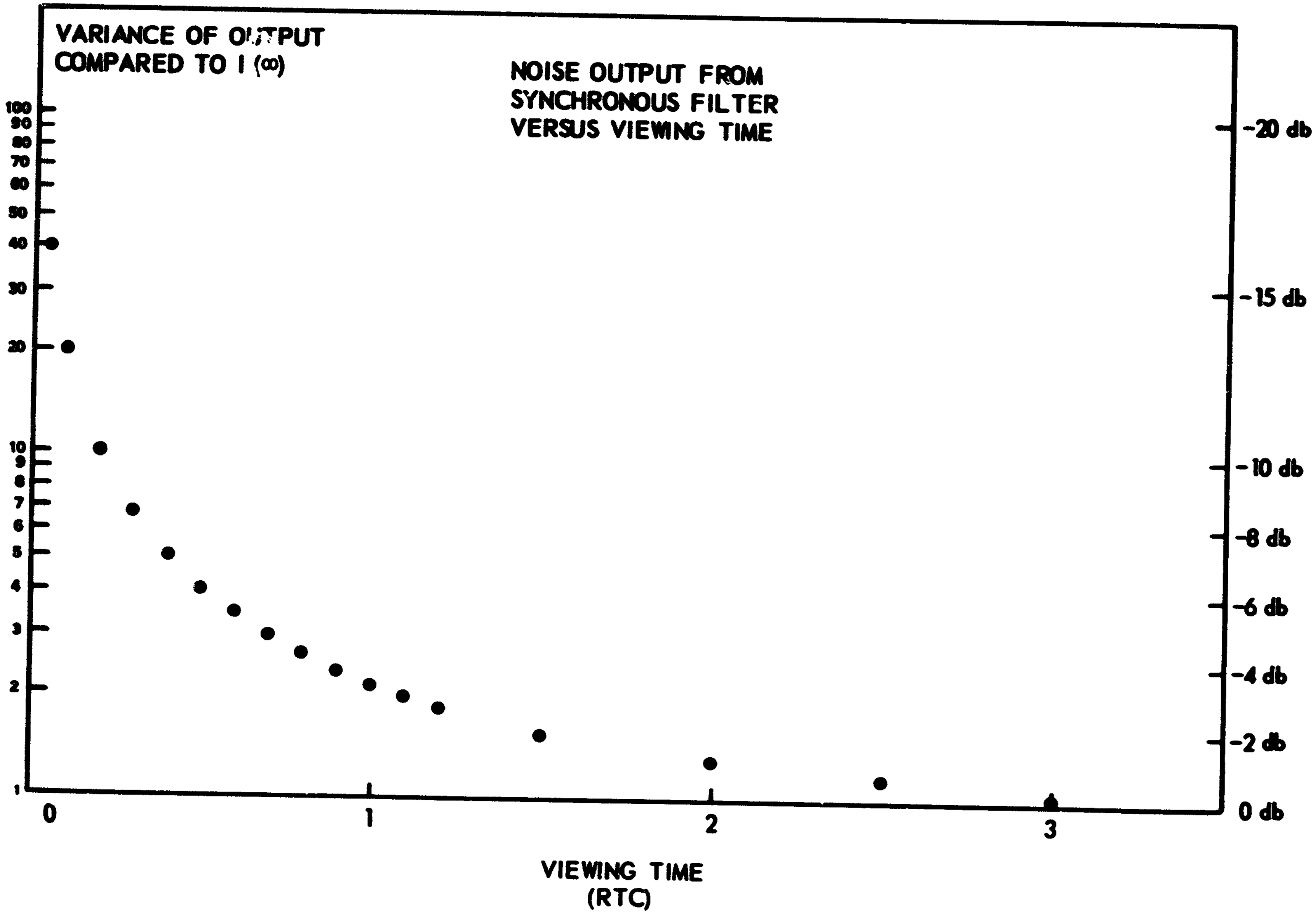


Figure 15. Synchronous Filter Improvement as a Function of Averaging Time

APPENDIX B

TYPICAL TIME OF COINCIDENCE (TOC) TABLE — CENTRAL PACIFIC CHAIN

The following is a TOC Table published by the USNO. Such tables can be used to determine all time of coincidences, in one year, for a LORAN-C chain, as well as the time difference between each UTC (USNO) second and the next GRP epoch transmitted by that chains Master station. TOC tables for all LORAN-C chains (although some chains are not presently synchronized), as well as station coordinages, emission delays, chain phase-errors (published weekly) and other bulletins may be obtained from:

Superintendent
U.S. Naval Observatory
Attn: Time Service Division
Washington, D. C. 20390

Reference:
Series 9 Publications — LORAN-C Bulletins
Series 4 Publications — Daily Phase Values

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

6 November 1970

TIME SERVICE ANNOUNCEMENT, SERIES 9 NO. 44

TIMES OF COINCIDENCE (NULL) EPHEMERIS for the CENTPAL PACIFIC
Loran-C Chain for the Year 1971

Reference: (a) Supplement No. 5 to Daily Phase Values of 30 September 1968

1. Time Service Announcements Series 9 are announcements concerning Loran-C.

2. The repetition rate of the Central Pacific chain is presently 49,900 µs, and the beginning of the first pulse of one of the groups is emitted at a particular second on the UTC time scale. That pulse is synchronised to the U. S. Naval Observatory Master Clock.

3. The times of coincidence of the beginning of the reference Loran-C pulse with the U. S. Naval Observatory Master Clock are found for each day by adding the values of Table 2 to the value of Table 1.

Example:

Assume that an operator monitoring a Loran-C station of the Central Pacific chain desires to make a synchronization check between the station clock and the Loran-C transmission at about 1800 UT on 14 July 1971.

From Table 2, the values near 1800 UT are:

H	M	S
17	52	51
18	01	10
18	09	29.

These are added to the value from Table 1 listed for 14 July 1971:

H	M	S
00	00	11

to give, for the time of interest, the times of coincidence between the beginning of the Loran-C reference pulse and the U. S. Naval Observatory Master Clock one-pulse-per-second, namely:

H	M	S
17	53	02
18	01	21
18	09	40.

4. Between the times of coincidence as given by Tables 1 and 2, the time difference between any one-pulse-per-second of the U. S. Naval Observatory Master Clock and the immediately following first (reference) pulse of a Loran-C group can be determined by using Table 3.

Example:

Assume that such a time difference was required at $17^h\ 59^m\ 59^s$ on 14 July 1971. From Tables 1 and 2 we found that the last null occurred at $17^h\ 53^m\ 02^s$. Therefore, the time at which the measurement was required would have occurred at $06^m\ 57^s$ after that last null.

From Table 3 we noted that the time corresponding to $06^m\ 57^s$ is 14,300 microseconds. This means that the beginning of the first pulse of a group of eight (the reference pulse) from that Loran-C station was transmitted 14,300 microseconds after $17^h\ 59^m\ 59^s$ on 14 July 1971.

GERNOT M. R. WINKLER
Director
Time Service Division

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S
JAN 1	0	3	21	FEB 1	0	7	13	MAR 1	0	6	25
2	0	2	8	2	0	6	0	2	0	5	12
3	0	0	55	3	0	4	47	3	0	3	59
4	0	8	1	4	0	3	34	4	0	2	46
5	0	6	48	5	0	2	21	5	0	1	33
6	0	5	35	6	0	1	8	6	0	0	20
7	0	4	22	7	0	8	14	7	0	7	26
8	0	3	9	8	0	7	1	8	0	6	13
9	0	1	56	9	0	5	48	9	0	5	0
10	0	0	43	10	0	4	35	10	0	3	47
11	0	7	49	11	0	3	22	11	0	2	34
12	0	6	36	12	0	2	9	12	0	1	21
13	0	5	23	13	0	0	56	13	0	0	8
14	0	4	10	14	0	8	2	14	0	7	14
15	0	2	57	15	0	6	49	15	0	6	1
16	0	1	44	16	0	5	36	16	0	4	48
17	0	0	31	17	0	4	23	17	0	3	35
18	0	7	37	18	0	3	10	18	0	2	22
19	0	6	24	19	0	1	57	19	0	1	9
20	0	5	11	20	0	0	44	20	0	8	15
21	0	3	58	21	0	7	50	21	0	7	2
22	0	2	45	22	0	6	37	22	0	5	49
23	0	1	32	23	0	5	24	23	0	4	36
24	0	0	19	24	0	4	11	24	0	3	23
25	0	7	25	25	0	2	58	25	0	2	10
26	0	6	12	26	0	1	45	26	0	0	57
27	0	4	59	27	0	0	32	27	0	8	3
28	0	3	46	28	0	7	38	28	0	6	50
29	0	2	33					29	0	5	37
30	0	1	20					30	0	4	24
31	0	0	7					31	0	3	11

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S
APR 1	0	1	58	MAY 1	0	7	3	JUN 1	0	2	36
2	0	0	45	2	0	5	50	2	0	1	23
3	0	7	51	3	0	4	37	3	0	0	10
4	0	6	38	4	0	3	24	4	0	7	16
5	0	5	25	5	0	2	11	5	0	6	3
6	0	4	12	6	0	0	58	6	0	4	50
7	0	2	59	7	0	8	4	7	0	3	37
8	0	1	46	8	0	6	51	8	0	2	24
9	0	0	33	9	0	5	38	9	0	1	11
10	0	7	39	10	0	4	25	10	0	8	17
11	0	6	26	11	0	3	12	11	0	7	4
12	0	5	13	12	0	1	59	12	0	5	51
13	0	4	0	13	0	0	46	13	0	4	38
14	0	2	47	14	0	7	52	14	0	3	25
15	0	1	34	15	0	6	39	15	0	2	12
16	0	0	21	16	0	5	26	16	0	0	59
17	0	7	27	17	0	4	13	17	0	8	5
18	0	6	14	18	0	3	0	18	0	6	52
19	0	5	1	19	0	1	47	19	0	5	39
20	0	3	48	20	0	0	34	20	0	4	26
21	0	2	35	21	0	7	40	21	0	3	13
22	0	1	22	22	0	6	27	22	0	2	0
23	0	0	9	23	0	5	14	23	0	0	47
24	0	7	15	24	0	4	1	24	0	7	53
25	0	6	2	25	0	2	48	25	0	6	40
26	0	4	49	26	0	1	35	26	0	5	27
27	0	3	36	27	0	0	22	27	0	4	14
28	0	2	23	28	0	7	28	28	0	3	1
29	0	1	10	29	0	6	15	29	0	1	48
30	0	8	16	30	0	5	2	30	0	0	35
				31	0	3	49				

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S
JUL 1	0	7	41	AUG 1	0	3	14	SEP 1	0	7	6
2	0	6	28	2	0	2	1	2	0	5	53
3	0	5	15	3	0	0	48	3	0	4	40
4	0	4	2	4	0	7	54	4	0	3	27
5	0	2	49	5	0	6	41	5	0	2	14
6	0	1	36	6	0	5	28	6	0	1	1
7	0	0	23	7	0	4	15	7	0	8	7
8	0	7	29	8	0	3	2	8	0	6	54
9	0	6	16	9	0	1	49	9	0	5	41
10	0	5	3	10	0	0	36	10	0	4	28
11	0	3	50	11	0	7	42	11	0	3	15
12	0	2	37	12	0	6	29	12	0	2	2
13	0	1	24	13	0	5	16	13	0	0	49
14	0	0	11	14	0	4	3	14	0	7	55
15	0	7	17	15	0	2	50	15	0	6	42
16	0	6	4	16	0	1	37	16	0	5	29
17	0	4	51	17	0	0	24	17	0	4	16
18	0	3	38	18	0	7	30	18	0	3	3
19	0	2	25	19	0	6	17	19	0	1	50
20	0	1	12	20	0	5	4	20	0	0	37
21	0	8	18	21	0	3	51	21	0	7	43
22	0	7	5	22	0	2	38	22	0	6	30
23	0	5	52	23	0	1	25	23	0	5	17
24	0	4	39	24	0	0	12	24	0	4	4
25	0	3	26	25	0	7	18	25	0	2	51
26	0	2	13	26	0	6	5	26	0	1	38
27	0	1	0	27	0	4	52	27	0	0	25
28	0	8	6	28	0	3	39	28	0	7	31
29	0	6	53	29	0	2	26	29	0	6	18
30	0	5	40	30	0	1	13	30	0	5	5
31	0	4	27	31	0	0	0				

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S	DATE 1971	TIME H	M	S
OCT 1	0	3	52	NOV 1	0	7	44	DEC 1	0	4	30
2	0	2	39	2	0	6	31	2	0	3	17
3	0	1	26	3	0	5	18	3	0	2	4
4	0	0	13	4	0	4	5	4	0	0	51
5	0	7	19	5	0	2	52	5	0	7	57
6	0	6	6	6	0	1	39	6	0	6	44
7	0	4	53	7	0	0	26	7	0	5	31
8	0	3	40	8	0	7	32	8	0	4	18
9	0	2	27	9	0	6	19	9	0	3	5
10	0	1	14	10	0	5	6	10	0	1	52
11	0	0	1	11	0	3	53	11	0	0	39
12	0	7	7	12	0	2	40	12	0	7	45
13	0	5	54	13	0	1	27	13	0	6	32
14	0	4	41	14	0	0	14	14	0	5	19
15	0	3	28	15	0	7	20	15	0	4	6
16	0	2	15	16	0	6	7	16	0	2	53
17	0	1	2	17	0	4	54	17	0	1	40
18	0	8	8	18	0	3	41	18	0	0	27
19	0	6	55	19	0	2	28	19	0	7	33
20	0	5	42	20	0	1	15	20	0	6	20
21	0	4	29	21	0	0	2	21	0	5	7
22	0	3	16	22	0	7	8	22	0	3	54
23	0	2	3	23	0	5	55	23	0	2	41
24	0	0	50	24	0	4	42	24	0	1	28
25	0	7	56	25	0	3	29	25	0	0	15
26	0	6	43	26	0	2	16	26	0	7	21
27	0	5	30	27	0	1	3	27	0	6	8
28	0	4	17	28	0	8	9	28	0	4	55
29	0	3	4	29	0	6	56	29	0	3	42
30	0	1	51	30	0	5	43	30	0	2	29
31	0	0	38					31	0	1	16

TABLE 2
ALL TOC'S IN A DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN-C CHAIN
49,900 MICROSECONDS/PERIOD

H	M	S	H	M	S	H	M	S
0	0	0	5	32	40	11	5	20
0	8	19	5	40	59	11	13	39
0	16	38	5	49	18	11	21	58
0	24	57	5	57	37	11	30	17
0	33	16	6	5	56	11	38	36
0	41	35	6	14	15	11	46	55
0	49	54	6	22	34	11	55	14
0	58	13	6	30	53	12	3	33
1	6	32	6	39	12	12	11	52
1	14	51	6	47	31	12	20	11
1	23	10	6	55	50	12	28	30
1	31	29	7	4	9	12	36	49
1	39	48	7	12	28	12	45	8
1	48	7	7	20	47	12	53	27
1	56	26	7	29	6	13	1	46
2	4	45	7	37	25	13	10	5
2	13	4	7	45	44	13	18	24
2	21	23	7	54	3	13	26	43
2	29	42	8	2	22	13	35	2
2	38	1	8	10	41	13	43	21
2	46	20	8	19	0	13	51	40
2	54	39	8	27	19	13	59	59
3	2	58	8	35	38	14	8	18
3	11	17	8	43	57	14	16	37
3	19	36	8	52	16	14	24	56
3	27	55	9	0	35	14	33	15
3	36	14	9	8	54	14	41	34
3	44	33	9	17	13	14	49	53
3	52	52	9	25	32	14	58	12
4	1	11	9	33	51	15	6	31
4	9	30	9	42	10	15	14	50
4	17	49	9	50	29	15	23	9
4	26	8	9	58	48	15	31	28
4	34	27	10	7	7	15	39	47
4	42	46	10	15	26	15	48	6
4	51	5	10	23	45	15	56	25
4	59	24	10	32	4	16	4	44
5	7	43	10	40	23	16	13	3
5	16	2	10	48	42	16	21	22
5	24	21	10	57	1	16	29	41

TABLE 2
ALL TOC'S IN A DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

CENTRAL PACIFIC LORAN-C CHAIN
49,900 MICROSECONDS/PERIOD

H	M	S	H	M	S
16	38	0	22	10	40
16	46	19	22	18	59
16	54	38	22	27	18
17	2	57	22	35	37
17	11	16	22	43	56
17	19	35	22	52	15
17	27	54	23	0	34
17	36	13	23	8	53
17	44	32	23	17	12
17	52	51	23	25	31
18	1	10	23	33	50
18	9	29	23	42	9
18	17	48	23	50	28
18	26	7	23	58	47
18	34	26			
18	42	45			
18	51	4			
18	59	23			
19	7	42			
19	16	1			
19	24	20			
19	32	39			
19	40	58			
19	49	17			
19	57	36			
20	5	55			
20	14	14			
20	22	33			
20	30	52			
20	39	11			
20	47	30			
20	55	49			
21	4	8			
21	12	27			
21	20	46			
21	29	5			
21	37	24			
21	45	43			
21	54	2			
22	2	21			

TABLE 3
INTERPOLATIONS FOR ALL SECONDS BETWEEN TOC'S

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

M	S	(µS)	M	S	(µS)	M	S	(µS)	M	S	(µS)	M	S	(µS)
0	1	47900	0	51	47700	1	41	47500	2	31	47300	3	21	47100
0	2	45900	0	52	45700	1	42	45500	2	32	45300	3	22	45100
0	3	43900	0	53	43700	1	43	43500	2	33	43300	3	23	43100
0	4	41900	0	54	41700	1	44	41500	2	34	41300	3	24	41100
0	5	39900	0	55	39700	1	45	39500	2	35	39300	3	25	39100
0	6	37900	0	56	37700	1	46	37500	2	36	37300	3	26	37100
0	7	35900	0	57	35700	1	47	35500	2	37	35300	3	27	35100
0	8	33900	0	58	33700	1	48	33500	2	38	33300	3	28	33100
0	9	31900	0	59	31700	1	49	31500	2	39	31300	3	29	31100
0	10	29900	1	0	29700	1	50	29500	2	40	29300	3	30	29100
0	11	27900	1	1	27700	1	51	27500	2	41	27300	3	31	27100
0	12	25900	1	2	25700	1	52	25500	2	42	25300	3	32	25100
0	13	23900	1	3	23700	1	53	23500	2	43	23300	3	33	23100
0	14	21900	1	4	21700	1	54	21500	2	44	21300	3	34	21100
0	15	19900	1	5	19700	1	55	19500	2	45	19300	3	35	19100
0	16	17900	1	6	17700	1	56	17500	2	46	17300	3	36	17100
0	17	15900	1	7	15700	1	57	15500	2	47	15300	3	37	15100
0	18	13900	1	8	13700	1	58	13500	2	48	13300	3	38	13100
0	19	11900	1	9	11700	1	59	11500	2	49	11300	3	39	11100
0	20	9900	1	10	9700	2	0	9500	2	50	9300	3	40	9100
0	21	7900	1	11	7700	2	1	7500	2	51	7300	3	41	7100
0	22	5900	1	12	5700	2	2	5500	2	52	5300	3	42	5100
0	23	3900	1	13	3700	2	3	3500	2	53	3300	3	43	3100
0	24	1900	1	14	1700	2	4	1500	2	54	1300	3	44	1100
0	25	49800	1	15	49600	2	5	49400	2	55	49200	3	45	49000
0	26	47800	1	16	47600	2	6	47400	2	56	47200	3	46	47000
0	27	45800	1	17	45600	2	7	45400	2	57	45200	3	47	45000
0	28	43800	1	18	43600	2	8	43400	2	58	43200	3	48	43000
0	29	41800	1	19	41600	2	9	41400	2	59	41200	3	49	41000
0	30	39800	1	20	39600	2	10	39400	3	0	39200	3	50	39000
0	31	37800	1	21	37600	2	11	37400	3	1	37200	3	51	37000
0	32	35800	1	22	35600	2	12	35400	3	2	35200	3	52	35000
0	33	33800	1	23	33600	2	13	33400	3	3	33200	3	53	33000
0	34	31800	1	24	31600	2	14	31400	3	4	31200	3	54	31000
0	35	29800	1	25	29600	2	15	29400	3	5	29200	3	55	29000
0	36	27800	1	26	27600	2	16	27400	3	6	27200	3	56	27000
0	37	25800	1	27	25600	2	17	25400	3	7	25200	3	57	25000
0	38	23800	1	28	23600	2	18	23400	3	8	23200	3	58	23000
0	39	21800	1	29	21600	2	19	21400	3	9	21200	3	59	21000
0	40	19800	1	30	19600	2	20	19400	3	10	19200	4	0	19000
0	41	17800	1	31	17600	2	21	17400	3	11	17200	4	1	17000
0	42	15800	1	32	15600	2	22	15400	3	12	15200	4	2	15000
0	43	13800	1	33	13600	2	23	13400	3	13	13200	4	3	13000
0	44	11800	1	34	11600	2	24	11400	3	14	11200	4	4	11000
0	45	9800	1	35	9600	2	25	9400	3	15	9200	4	5	9000
0	46	7800	1	36	7600	2	26	7400	3	16	7200	4	6	7000
0	47	5800	1	37	5600	2	27	5400	3	17	5200	4	7	5000
0	48	3800	1	38	3600	2	28	3400	3	18	3200	4	8	3000
0	49	1800	1	39	1600	2	29	1400	3	19	1200	4	9	1000
0	50	49700	1	40	49500	2	30	49300	3	20	49100	4	10	48900

TABLE 3
INTERPOLATIONS FOR ALL SECONDS BETWEEN TOC'S

CENTRAL PACIFIC LORAN C CHAIN
49,900 MICROSECONDS/PERIOD

M	S	(µS)	M	S	(µS)	M	S	(µS)	M	S	(µS)	M	S	(µS)
4	11	46900	5	1	46700	5	51	46500	6	41	46300	7	31	46100
4	12	44900	5	2	44700	5	52	44500	6	42	44300	7	32	44100
4	13	42900	5	3	42700	5	53	42500	6	43	42300	7	33	42100
4	14	40900	5	4	40700	3	54	40500	6	44	40300	7	34	40100
4	15	38900	5	5	38700	5	55	38500	6	45	38300	7	35	38100
4	16	36900	5	6	36700	5	56	36500	6	46	36300	7	36	36100
4	17	34900	5	7	34700	5	57	34500	6	47	34300	7	37	34100
4	18	32900	5	8	32700	5	58	32500	6	48	32300	7	38	32100
4	19	30900	5	9	30700	5	59	30500	6	49	30300	7	39	30100
4	20	28900	5	10	28700	6	0	28500	6	50	28300	7	40	28100
4	21	26900	5	11	26700	6	1	26500	6	51	26300	7	41	26100
4	22	24900	5	12	24700	6	2	24500	6	52	24300	7	42	24100
4	23	22900	5	13	22700	6	3	22500	6	53	22300	7	43	22100
4	24	20900	5	14	20700	6	4	20500	6	54	20300	7	44	20100
4	25	18900	5	15	18700	6	5	18500	6	55	18300	7	45	18100
4	26	16900	5	16	16700	6	6	16500	6	56	16300	7	46	16100
4	27	14900	5	17	14700	6	7	14500	6	57	14300	7	47	14100
4	28	12900	5	18	12700	6	8	12500	6	58	12300	7	48	12100
4	29	10900	5	19	10700	6	9	10500	6	59	10300	7	49	10100
4	30	8900	5	20	8700	6	10	8500	7	0	8300	7	50	8100
4	31	6900	5	21	6700	6	11	6500	7	1	6300	7	51	6100
4	32	4900	5	22	4700	6	12	4500	7	2	4300	7	52	4100
4	33	2900	5	23	2700	6	13	2500	7	3	2300	7	53	2100
4	34	900	5	24	700	6	14	500	7	4	300	7	54	100
4	35	48800	5	25	48600	6	15	48400	7	5	48200	7	55	48000
4	36	46800	5	26	46600	6	16	46400	7	6	46200	7	56	46000
4	37	44800	5	27	44600	6	17	44400	7	7	44200	7	57	44000
4	38	42800	5	28	42600	6	18	42400	7	8	42200	7	58	42000
4	39	40800	5	29	40600	6	19	40400	7	9	40200	7	59	40000
4	40	38800	5	30	38600	6	20	38400	7	10	38200	8	0	38000
4	41	36800	5	31	36600	6	21	36400	7	11	36200	8	1	36000
4	42	34800	5	32	34600	6	22	34400	7	12	34200	8	2	34000
4	43	32800	5	33	32600	6	23	32400	7	13	32200	8	3	32000
4	44	30800	5	34	30600	6	24	30400	7	14	30200	8	4	30000
4	45	28800	5	35	28600	6	25	28400	7	15	28200	8	5	28000
4	46	26800	5	36	26600	6	26	26400	7	16	26200	8	6	26000
4	47	24800	5	37	24600	6	27	24400	7	17	24200	8	7	24000
4	48	22800	5	38	22600	6	28	22400	7	18	22200	8	8	22000
4	49	20800	5	39	20600	6	29	20400	7	19	20200	8	9	20000
4	50	18800	5	40	18600	6	30	18400	7	20	18200	8	10	18000
4	51	16800	5	41	16600	6	31	16400	7	21	16200	8	11	16000
4	52	14800	5	42	14600	6	32	14400	7	22	14200	8	12	14000
4	53	12800	5	43	12600	6	33	12400	7	23	12200	8	13	12000
4	54	10800	5	44	10600	6	34	10400	7	24	10200	8	14	10000
4	55	8800	5	45	8600	6	35	8400	7	25	8200	8	15	8000
4	56	6800	5	46	6600	6	36	6400	7	26	6200	8	16	6000
4	57	4800	5	47	4600	6	37	4400	7	27	4200	8	17	4000
4	58	2800	5	48	2600	6	38	2400	7	28	2200	8	18	2000
4	59	800	5	49	600	6	39	400	7	29	200	8	19	49900
5	0	48700	5	50	48500	6	40	48300	7	30	48100			