J. P. VAN ETTEN

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CLARINET PILGRIM SYSTEM

WALTER N. DEAN

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JIM VAN ETTEN
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CLARINET PILGRIM

Clarinet Pilgrim is a system which superimposes U.S. Navy Fleet broadcast on the Loran-C pulse transmissions. Its purpose is to provide a parallel link to improve the reliability of Navy communications in areas covered by Loran-C. The system is designed to provide this capability with minimal effect on the navigational characteristics of the Loran-C system. Clarinet Pilgrim has been installed in the Northwest Pacific Loran-C chain (WESPAC), where it has been in service on a continuous basis for over three years.

NAVY FLEET BROADCAST

The Navy Fleet Broadcast being transmitted by the Clarinet Pilgrim is a radio teletype stream of binary data. Identical broadcasts are transmitted from VLF, LF, and HF stations in locations such as Hawaii, Guam, Japan, and Australia using conventional FSK transmission modes.

CLARINET PILGRIM MODULATION

The Loran-C pulses are pulse position modulated by the communication information. Each data bit is translated into a change-in-position of one Loran-C pulse. Identical data are sent from each station in a chain.

The Loran-C transmissions consist of groups of 8 pulses transmitted from each station at rates varying between 10 and 20 groups per second, depending on the particular chain configuration. This means that there is a minimum of 80 and a maximum of 160 pulses transmitted from each station per second. For this reason it is not necessary to modulate all of the pulses in order to transmit the data. Table 1 shows the number of pulses to be modulated for each repetition rate. It is seen that in all cases more pulses are available to be modulated than are required to handle the data. Therefore, the Clarinet Pilgrim system inserts filler or "sync" words into the transmitted data in order to maintain the data stream in the Loran system. The table also indicates the ratio of sync words to data words. These sync words are recognized by the data receiver and stripped out of the data stream before it is reconstituted. The output from the system is, except for errors and transmission delay, identical to the input data.

TABLE 1. DATA RATE CAPABILITY

Rate	Groups/Sec	Pulses Mod	Pulses/Sec	Sync Word Ratio
SS	10	6	60	1/5
SL	12.5	5	62.5	1/4
SH	16-2/3	4	66-2/3	1/3
S	20	3	60	1/5

SYSTEM OPERATION

All stations in a Loran-C chain transmit identical data, obtained by a composite of the best means available (see Figure 1). A receiver in the area normally receives the three strongest stations and demodulates the data from each. Then, by simple "majority vote" technique, the three are combined to a single best estimate of the data. The power of the majority vote technique can be illustrated by the following example: Three stations received with error rates of .04, .02, and .02 will have a majority vote error rate of .002.

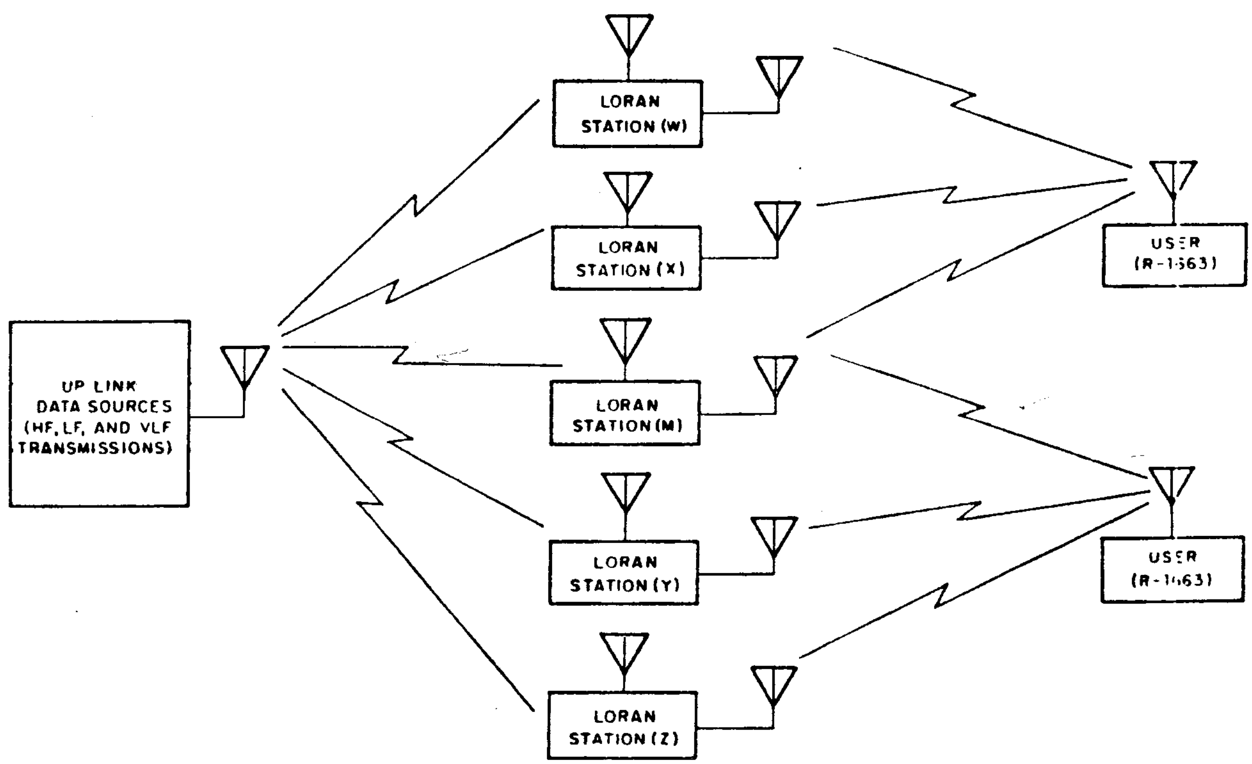

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Figure 1. Data Flow Through the Loran System

Because the detection of the Clarinet Pilgrim modulation depends only on measuring the change of phase from pulse to pulse, it is not necessary to distinguish between groundwave and skywave propagated modes; and in fact it is most desirable only to obtain the strongest part of the signal. For this reason, it is practical to use a receiver whose pass-band is narrow and quite steep-sided so as to completely reject interference signals away from 100 KHz. Accordingly, the receiver utilizes a 6-pole, 6 KHz bandwidth filter, which has been determined to be reasonably close to optimum for this application.

Propagation of the 100 KHz signal by skywaves is pronounced at ranges beyond 350 nautical miles at night and 500 nautical miles in the daytime. Figure 2 shows the relative amplitude of groundwave and skywave signals as a function of distance from the transmitters. It is obvious, particularly at night, that a considerable gain in signal strength is obtained by taking advantage of skywave propagation.

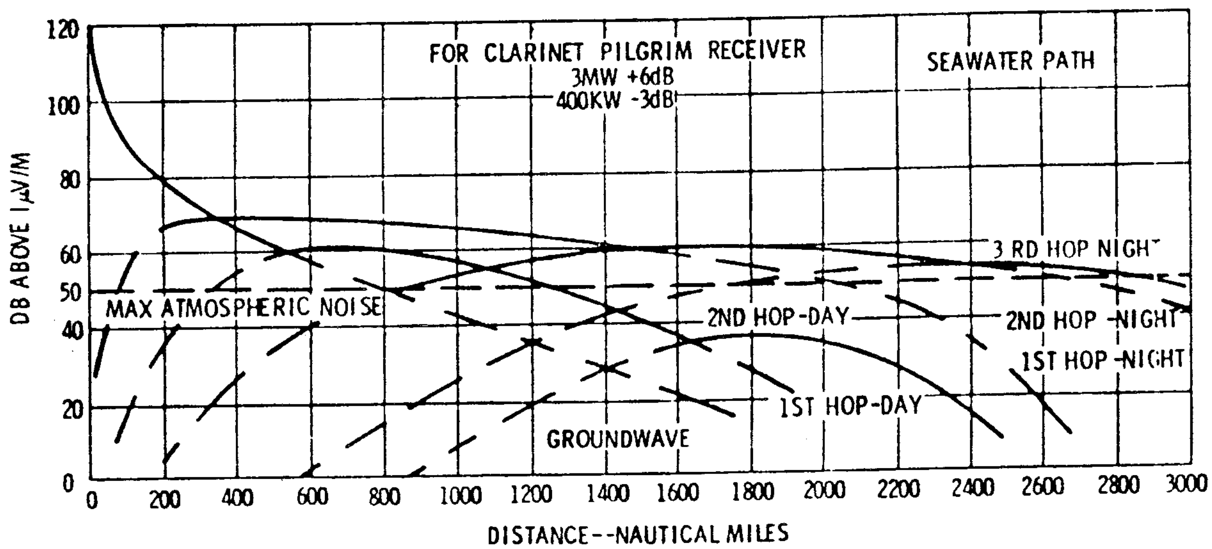

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Figure 2. Skywave Field Intensity Vs Range at 100 kHz

The principal sources of errors in the system are atmospheric noise and crossing-rate interference. Noise amplitude exhibits extreme variability in time and space. CCIR Report 322* predicts a worst-case noise (exceeded less than one percent of the time) in the order of 50 dB above one-microvolt per meter in the Western Pacific. Worst-case signal-to-noise ratios can be derived from Figure 2. The resulting error rate can be predicted by reference to Figure 3, which was developed with specific reference to atmospheric noise with the amplitude distribution expected in the Clarinet Pilgrim receiver.

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* C.C.I.R. Report 322 "World Distribution and Characteristics of Atmospheric Radio Noise"

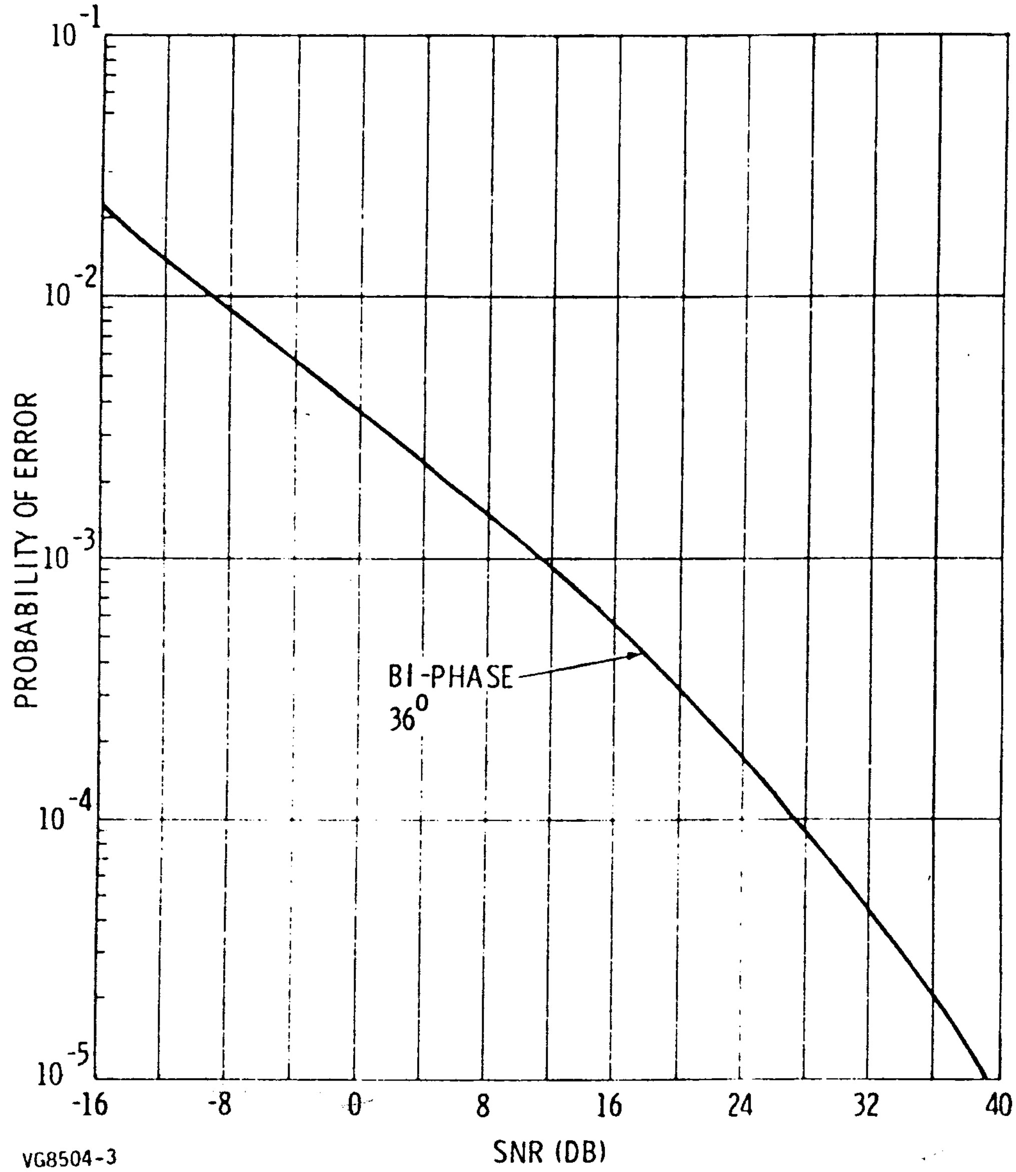

Figure 3. Bit Error Probability -- Atmospheric Noise V_D = 24 dB

Loran-C signals on other repetition rates will produce errors when they coincide in time with the desired signals. Figure 4 shows the single station error rate as a function of relative amplitude. Analysis of errors due to crossing signals is complicated by the fact that a single crossing signal can interfere with only one station at a time, thus majority vote would completely eliminate its effect, in the absence of other errors. Due to these low sources of error, system performance in the Western Pacific has been reported highly satisfactory.

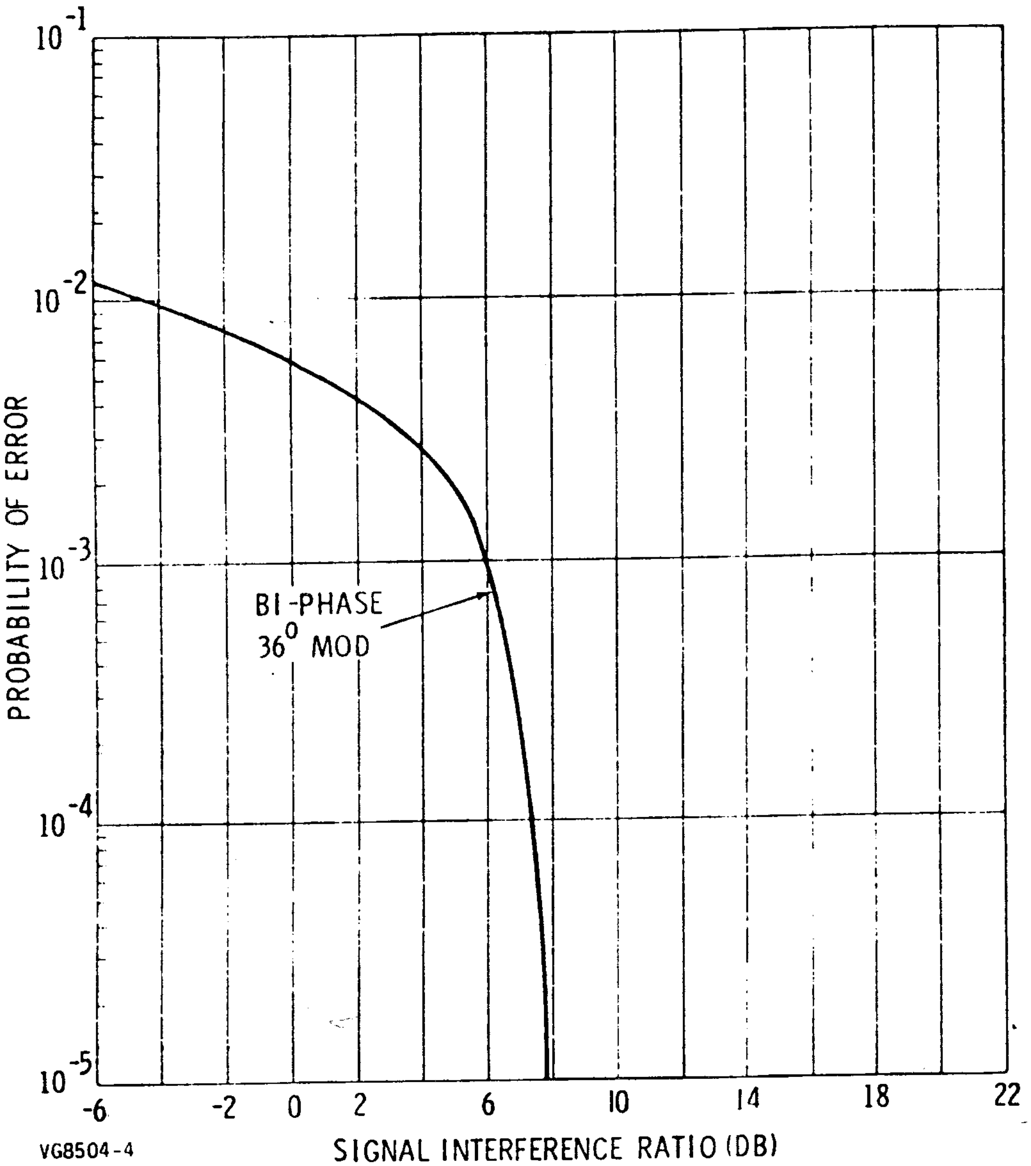

Figure 4. Bit Error Probability Crossing Rate Interference

SYSTEM DESIGN

The Clarinet Pilgrim system is designed to handle the standard U.S. Navy traffic, but it is also capable of recognizing and processing start-stop teletype and Morse code CW. The Transmitter Control Set designated AN/FRQ-17 and located at the Loran-C transmitting stations incorporates five radio communication receivers for reception of the uplink data. The number of receivers actually in use depends on the availability and quality of the data as received over the various conventional communication channels.

A specially built Signal Data Converter takes the audio output of each receiver and converts it to digital form. The converter is designed to process either FSK or Morse code CW interchangeably and automatically.

While the synchronous bit stream is the usual data mode, it is necessary to process either the CW or asynchronous teletype. In order to do this the Receiver Signal Selector unit takes the data from each Signal Data Converter, determines which data mode is being received, and alerts the operator if Morse Code or asynchronous teletype is being received.

Signal Comparator

The Signal Comparator accepts the outputs to the corresponding receiver signal selector channels and delays each signal by an appropriate amount so that all data streams are in bit-by-bit correlation. The output of this unit is a single-binary data stream which represents the majority vote of the data going into the unit. The Signal Comparator has a total of seven channels in order to accept data from two other Loran stations which are transmitting Clarinet Pilgrim data.

Digital Data Receiver

The Digital Data Receiver (R-1663(XN-1)/UR) is a manual-acquisition automatic phase-tracking Loran receiver with additional circuitry to detect and reclock the Clarinet Pilgrim data. Figure 5 is a simplified block diagram of the receiver. The RF amplifier hard-limits the received signal, which is then tracked in a proportional phase-lock loop. The phase-lock loop not only maintains phase-lock on the average phase of each of the received signals but also provides a digital output representing the phase deviation of each of the signals from the average phase. The data for each of three stations is fed to the data buffer, where the sync words are identified and discarded, and then to the correlator where the difference in data timing is compensated for and the majority vote taken of the data from the available stations in order to obtain the most reliable output data. Provision is made to input two auxiliary data sources (which may be conventional radio receiver outputs) to be included in the majority vote and thereby improve the reliability of the output.

The Digital Data Receiver, included as part of the Transmitter Control Set, provides the following two functions:

(1) Generates timing voltages to the modulator control unit so that the data to the modulator has the proper timing for the selected Loran pulses to be modulated

(2) Monitors two other Loran stations in the chain and demodulates the data received from each

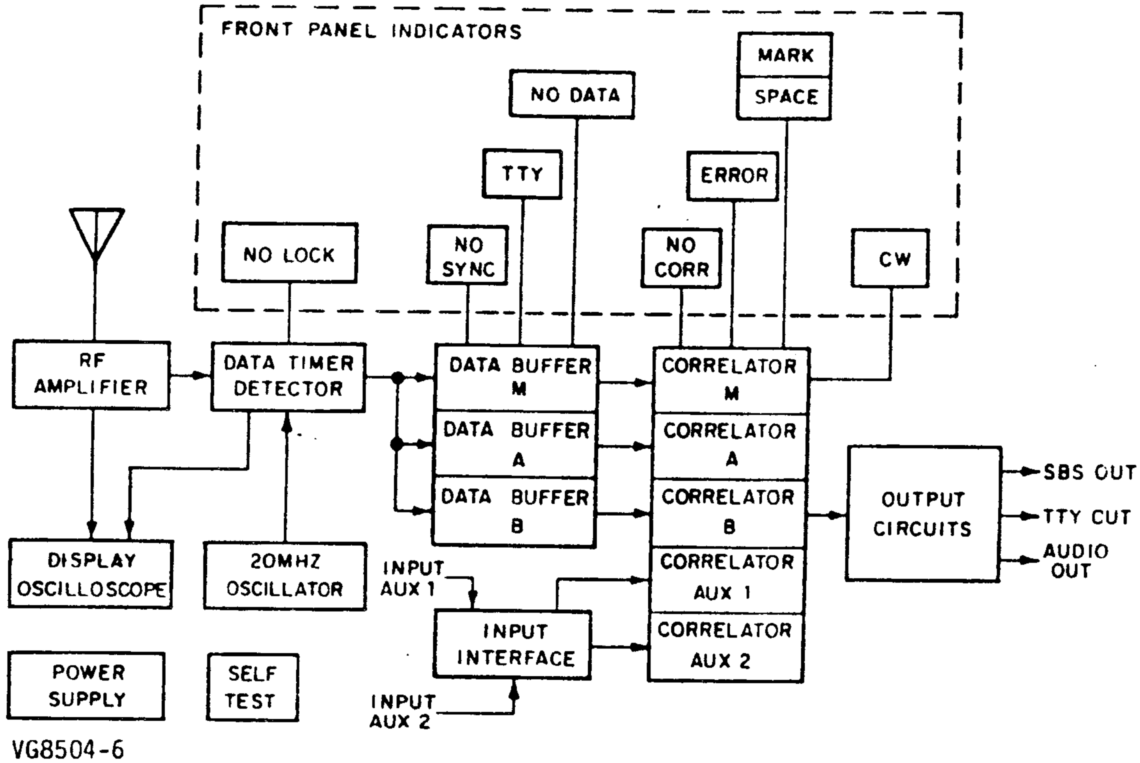

Figure 5. Digital Data Receiver R-1663 (XN-1)/UR Block Diagram

Modulation Control Unit

The Modulator Control Unit performs the following two basic functions:

(1) Clocks the data from the Signal Comparator to bring it into synchronism with Loran pulse timing

(2) Adds sync words at appropriate times when the input data rate has fallen sufficiently behind the Loran pulse rate

In addition to this, it has alarm circuits which keep track and warn of out-of-tolerance conditions.

EFFECT ON NAVIGATION

One of the primary concerns in the design and utilization of Clarinet Pilgrim is its effect on the navigation capabilities of the Loran-C system. The effects on navigation can be grouped into the following three categories:

(1) Random fluctuations in phase measurements
(2) Phase measurement offsets
(3) Change in sensitivity of hard limited receivers

The installation of the Clarinet Pilgrim system in the Western Pacific produced no noticeable effect on navigation performance. Laboratory tests on the AN/BRN-5 linear receiver and the AN/UPN-35 hard limiting receiver indicate no significant degradation of performance. The following analysis will show why this is so.

Phase Fluctuations

The Clarinet Pilgrim system as implemented shifts the Loran-C pulses forward or back precisely one microsecond in response to the data bits in the communication stream. Because these shifts occur in a random manner, certain groups of pulses will have offsets in one direction or the other to produce a noise component to the phase measurement. As a result, a small amount of random fluctuation is present even in extremely good signal-to-noise ratios. In poorer signal-to-noise ratios there is a slight decrease in the effective signal-to-noise ratio. The important consideration is the magnitude of this effect and its corresponding effect on navigation accuracy.

The fluctuation effect can be calculated on the assumption that all the 64 6-bit "words" are equally probable and that the random fluctuation is a function of the RMS deviation set up by these groups of 6-bit words. The calculation for 6-bit words (see in Table 2) produces an RMS value of 2.45.

With a 1 microsecond shift, modulating 6 out of 8 pulses, on the SS basic rate, every sixth word is a sync word which has zero offset. Then, the RMS fluctuation per group is 2.45/8 x 6/5 = .255 microseconds. A typical receiver with a 10 second averaging time would then see a fluctuation of .0255 microseconds.

TABLE 2. CALCULATION OF RMS FLUCTUATION

N	e	Ne^2
20	0	0
30	±2	120
11	±4	191
2	±6	72
64		384

$$RMS = \sqrt{\frac{384}{64}} = 2.45$$

At faster Loran repetition rates this fluctuation can be further reduced. For example, at SL rate, only five pulses need be modulated to handle the required data, therefore the sixth pulse may be used to balance the individual groups or to reduce the unbalance. As a result, the 25 nanosecond RMS fluctuation is reduced to 13 nanoseconds at the SL rate.

To translate the noise fluctuation into position error, it is necessary to consider the geometry of the situation. In the case where signals are strong and the 25 nanosecond fluctuation might be the dominant fluctuation error, the geometry is such that this would be equivalent to a position error in the order of 25 feet. On the other hand, at long ranges the geometry may be poor and one might expect a signal-to-noise ratio in the order of -10 dB. Under these conditions a typical receiver would show a fluctuation due to noise at 63 nanoseconds which corresponds to a position error of 250 feet. With the modulation superimposed the random fluctuations would increase to 77 nanoseconds or a position error of 305 feet. This is an increase in position error of less than 22% and could be compensated for by an increase in averaging time from 10 seconds to 15 seconds. It should be noted that the 77 nanoseconds is only a part of the error budget for normal Loran-C operation.

Phase Measurement Offset

The modulation also introduces a small offset in the phase reading when processed by a linear receiver. This occurs because the phase measurements are made on the rising edge of the pulse, and the amplitude of the error sample when the phase is advanced is larger than the amplitude of the error sample when the phase is retarded. Therefore, the phase position which balances these two amplitudes is offset from the true zero. This is compensated for at each of the transmitters by the cycle comp servo, which maintains constant the average phase of the transmitted pulses. Any linear receiver with the same bandwidth would see precisely the same phase that is transmitted. Linear receivers with different bandwidths would see slightly different phase conditions. For example, the AN/ARN-92 would show a phase difference of approximately 8 nanoseconds*. This difference would be identical on all three stations and would not enter into the time difference measurement.

Hard-limited receivers would measure the actual phase zero instead of the average of the two amplitudes samples and would therefore exhibit an offset of approximately 60 nanoseconds. Again, this effect is identical on all signals and no effect on time difference is observed.

Effect on Hard-Limiting Receivers

There has been considerable speculation regarding the possible effects of Clarinet Pilgrim modulation on the performance of hard limiting receivers, including rumors of a "dead spot" and effects on automatic search. Theoretical analysis supported by laboratory experiments has shown these fears to be unfounded.

The performance of the hard-limiting receiver can be analyzed by reference to Figure 6. This shows the distribution of phase fluctuations as a function of signal-to-noise ratio. For example, in a +20 dB signal-to-noise condition, 90% of the phase fluctuations will be less than 0.6

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*Contract DOT-CG-00632-A Final Techanical Report "Loran-C Phase Modulation Study".

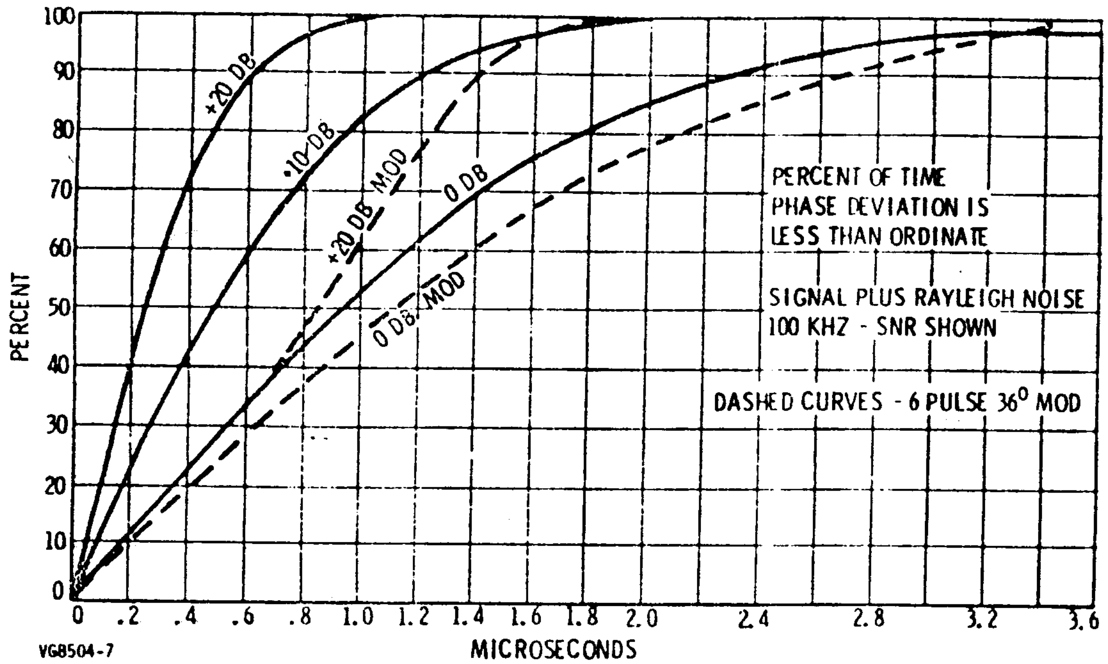

Figure 6. Percent of Time Phase Deviation

microseconds and 99% will be less than 1 microsecond. This means that in a hard limiting receiver if a phase offset of .6 microsecond were injected under these conditions, 90% of the samples seen by the servo loop would be in the proper phase direction to drive the servo towards the new corrected reading. Observe now that with zero dB signal-to-noise ratio, only 25% of the phase samples give the correct polarity to drive it towards the proper reading. Therefore, the servo will exhibit a more sluggish response and will take approximately 4 times as long to reach zero error condition. If, for example, all of the pulses transmitted were modulated ±1 microsecond, then errors of .2 microsecond would receive a net correct servo signal from less than 1% of the samples, thus resulting in very sluggish operation and the appearance of a dead spot. However, when the signal-to-noise ratio is 0 dB, then 50% of the phase samples will have an inherent phase-error greater than 1 microsecond. Therefore, superimposing modulation of 1 microsecond upon these samples would have very little effect on the servo operation.

Clarinet Pilgrim modulates only six of the eight pulses, thus leaving one-fourth of the pulses available for normal operation even when the signal-to-noise ratio is extremely high. The response of the hard-limiting receiver where the signal-to-noise ratio is +20 dB and six of the eight pulses are modulated ±1 microsecond, is shown as the dotted curve of Figure 6. This shows that the dynamic performance of the hard-limiting receiver in the presence of Clarinet Pilgrim modulation is affected by trivial amounts which will be impossible to observe. The effect on dynamic response of merely changing signal-to-noise ratio is much greater than the effect of adding 6-pulse modulation.

The search process is also affected by phase shift of the signals, whether by modulation or by noise. The modulation is random with respect to the Loran phase code; therefore, except for its distribution, it appears as noise. For that reason, it is instructive to analyze the distribution of phase with and without modulation. Figure 7 shows the distribution with 36 degrees modulation for +20 dB, +10 dB, and 0 dB SNR. For comparison, the distribution for 0 dB with no modulation is shown with each. The similarity of the distributions makes it obvious that the search characteristics with modulation and with any SNR will be similar to the characteristics at 0 dB and no modulation.

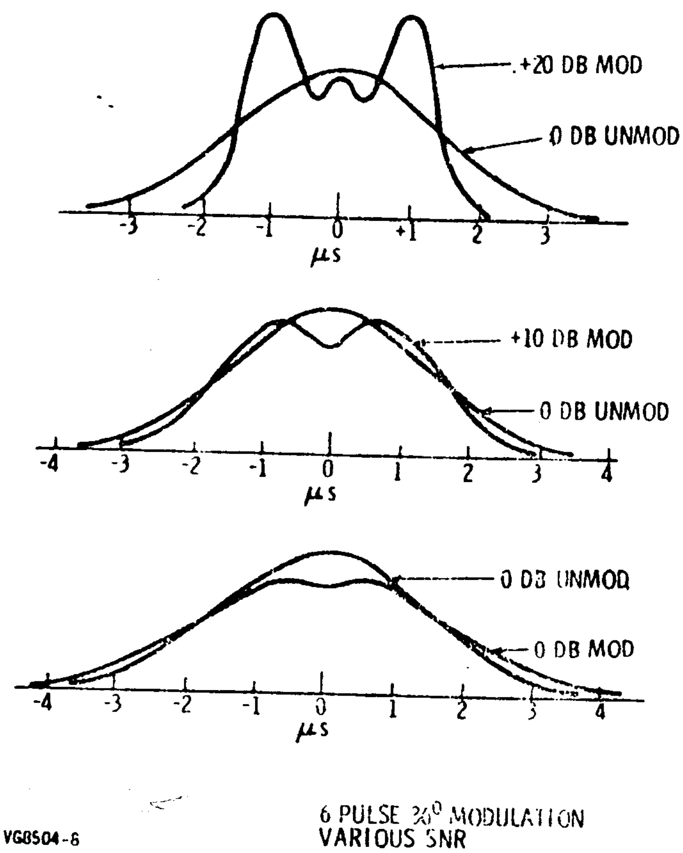

Figure 7. Distribution of Phase

SYSTEM IMPLEMENTATION

The system was first installed in the WESPAC chain in the fall of 1968, when feasibility tests were conducted. The present equipment was sent out to the five stations in November 1969. The Navy conducted technical and operational evaluation of the system during 1970 and reported it provided "100 percent availability". It has been operated continuously since then, with navigation users reporting no observable change in performance.

EXAMPLE OF OPERATION

800 MILES FROM STATIONS

100 NS = 400 FT POSITION ERROR

ERROR BUDGET

WITHOUT CLARINET PILGRIM

STATION SYNCHRONIZATION	50 NS
PROPAGATION VARIATION	60 NS
RECEIVER INSTRUMENTATION	50 NS
NOISE FLUCTUATION (-10 DB)	63 NS
RSS	112 NS

448 FT FIX ERROR

WITH CLARINET PILGRIM

STATION SYNCHRONIZATION	50 NS
PROPAGATION VARIATION	60 NS
RECEIVER INSTRUMENTATION	50 NS
NOISE FLUCTUATION	77 NS
RSS	116 NS

464 FT FIX ERROR