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CYCLE MATCHING FOR STANDARD LORAN

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CYCLE MATCHING FOR STANDARD LORAN

by

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July 1947

Problem No. 39R04-18

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CONTENTS

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ABSTRACT

This report discusses the requirements of a loran cycle-matching system and presents the results of observations conducted with laboratory loran cycle-matching equipment.

The present method of maintaining synchronism in a loran system is to match pulse envelopes at the slave station. With the development of crystal-controlled transmitters, cycles may be used for matching instead of pulse envelopes. An investigation was conducted to determine what degree of improvement might be expected fromccycle matching and what factors would be involved. A simple method of cycle matching was developed to permit the study of the synchronization errors introduced at the slave station and the limitations of the system. It was found that errors due to matching were reduced. When noise was on the screen of the oscilloscope there was outstanding improvement in the maintenance of synchronism, but with the method of presentation used, the uncertainity of the choice of the cycle to be used for matching was too great to make the system entirely satisfactory.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

CYCLE MATCHING FOR STANDARD LORAN

INTRODUCTION

Loran is a system of position determination, on the sea or in the air, by reception of radio signals from transmitting stations of known position. These stations operate in pairs, one of which is known as the "master" and the other the "slave". A navigator must receive signals from at least two pairs of stations before a position determination can be made.

Loran transmitting stations emit a steady succession of short pulses (about 40 microseconds long) which travel outward in all directions. The radio frequencies on which present transmitters operate are about two megacycles with a peak power of about seventy kilowatts.

The navigator obtains his position by measuring the difference of time of arrival of signals from a pair of stations. This locates him on a spherical hyperbola with one of the stations of the pair as the focus. Position on another spherical hyperbola is obtained by using a different pair of stations. Then by using a set of especially prepared charts he is able to find his position.

In order that an accurate determination of difference of time of arrival can be made by the navigator the stations must be accurately synchronized. Synchronism is done at the slave station. Here an accurate time difference is maintained between the pulses of the slave and master stations. This is done by an automatic synchronizer or by an operator. This is of prime importance to the satisfactory operation of the system since the charts are based on given time delays at the slave station.

Loran transmitters currently in use are of the pulsed oscillator type, which do not have a fixed time relation between the radio-frequency cycles and the pulse envelope.

With the development of Crystal Oscillator-Power Amplifier (COPA) transmitters, in which the radio-frequency cycles are fixed in relation to the pulse envelope, cycle matching will be possible at the shore stations and aboard ships.

In accordance with reference (1) *, this report discusses in the following paragraphs the general requirements of a standard loran cycle matching system as well as the improvement expected in the matching error. The data taken on a laboratory system to determine the errors of deviation for cycle matching and pulse envelope matching are also presented in this report.

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* BuShips ltr. - O-NRL Serial C-935-1995a of 15 September 1945 to NRL. Assignment of Problem.

All measurements were made in the laboratory. (See Figs. 1, 2 and 3). It was not possible to make field tests as equipment for so doing was not available. It is to be expected, however, that the same order of improvements will be obtained in the field as in a laboratory loran system.

CYCLE MATCHING AT STANDARD LORAN FREQUENCIES

The first requirement of a loran cycle-matching system is that the pulse repetition rate and the radio frequency carrier be controlled by the same source. This is accomplished by using the loran timer crystal as the controlling element of the radio frequency as well as the pulse repetition rate. Transmitters that operate on this principle are already in development, (reference 2).†

In this type of transmitter, the timer oscillator frequency is multiplied to the desired radio frequency. It is then pulsed by the timer and amplified to the desired level. A loran signal whose frequency is accurately known will then be transmitted and the r-f cycles will bear a fixed relation to the pulse envelope.

With this method of operation the operator at the slave station would be able to keep both the repetition rate and the radio frequency equal to that of the master station. The drifting of a pulse across the screen of the "fast scope" at the slave station would indicate a deviation of the radio frequency as well as pulse repetition rate. When a correction was applied to stop this drift by a change of the crystal oscillator frequency both the radio frequency and pulse-repetition rate would be corrected to that of the master station.

If the timer receiver now presents an unrectified pulse on the fast scope of the synchronization indicator, the slave and master station can be matched cycle for cycle and some improvement will be obtained in the slave-holding synchronism. (See Figs. 4 and 5). This type of matching, however, required that corresponding cycles in the remote and local pulses can be identified for matching.

The frequency of standard loran is of the order of two megacycles per second so it would not be practicable to use this frequency as a presentation on the fast scope of the synchronization indicator because of the short duration of each cycle (approximately 0.5 microsecond) and the consequent difficulty of cycle identification. A superheterodyne receiver can be used if the injection frequency bears a fixed phase and frequency relation to both the slave and master carrier frequencies. The injection frequency must, therefore, be derived from the timer crystal oscillator in a manner, similar to that of the radio frequency; and the intermediate frequency must be chosen so that the cycles can be identified and a mis-match of one cycle can be readily seen.

When the pulses are matched under these conditions any deviation from the matched state can be easily detected as a drift of the remote cycles across the screen of the slave synchronization indicator.

The use of cycle matching and a superheterodyne receiver, controlled by the timer crystal, increases the ability to detect a small mis-match in the pulse envelopes. This is partly because the i-f cycles of the remote pulse drift at a greater rate than the pulse

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† NRL ltr. C-S67-9/10(1210-MVH) C-1210-99/46 of 3 April 1946 to BuShips. Enclosure (A). NRL Report R-2781, "Considerations in the Design of two Mc Loran Transmitters Intended to Reduce Side-Bands and Permit Cycle-Matching Operation".

envelope. It is also true when the phase shifter of the local timer is turned. Since the injection frequency is derived from the crystal oscillator its shift in time will be equal to that of its 50 kc frequency. The number of cycles of shift, however, will depend on the frequency multiplication. When the injection frequency is mixed with the radio frequency the phase shift of the intermediate frequency will be equal to that of the injection frequency, but since the trace of the "fast scope" is also shifted in time when the phase shifter is turned the number of intermediate frequency cycles corresponding to this time must be added or subtracred to obtain the apparent number of cycles shifted. This can be shown as follows:

In the case of Model C, C-1 or UJ timers which have 50 kc crystals: Let Z be the radio frequency and Y be the intermediate frequency, both in megacycles. With one turn of the phase shifter dial the 50 kc is "shifted" one cycle.

The intermediate frequency will then be shifted $\frac{(Z \pm Y)10^6}{5 \text{ X } 10^4}$ cycles

But when the phase shifter dial is rotated one turn, the trace of the timer scope is shifted 20 microseconds in time with respect to the remote signal. Therefore, the apparent shift of i-f cycles will be the actual number of cycles shift plus or minus the number of cycles in 20 microseconds.

Cycles shift (apparent) =

$$\left[\frac{(Z \mp Y)10^6}{5 \text{ X } 10^4} \; \frac{10^{-6}}{Y} \pm 20 \text{ X } 10^{-6} \right] Y \text{ X } 10^6$$

Cycles shift (apparent) = 20 x Z

This is then the ratio of the 50 kc oscillator frequency to the radio frequency. As is to be expected, since actually it is the oscillator frequency that is being beaten with the radio frequency, the cycle shift depends only on this ratio.

From this it can be seen that the number of cycles shift across the screen of the synchronization indicator will be independent of the intermediate frequency. The shift on the screens of timers that use 100 kc crystals would be 10 x Z. This is true because the injection frequency is shifted only one-half as much with one turn of the phase shifter.

Now since the number of cycles shifted with one turn of the phase shifter is independent of the intermediate frequency the actual shift of a cycle in time, which corresponds to a given displacement on the screen, will be inversely proportional to the intermediate frequency. This shift in time will be:

$$\frac{\text{cycles shift}}{\text{i.f. in Mcs.}} = \text{microseconds shift of one cycle.}$$

If the phase shifter is turned so as to shift the remote pulse envelope one microsecond, the number of cycles shift of the intermediate frequency will be equal to:

$$\frac{\text{Number of cycles shifted for one rotation of phase shifter}}{\text{Shift of envelope in microseconds for one rotation of phase shifter}}$$

From this it can be seen that some magnification of error will result by using the mismatch of cycles provided the proper intermediate frequency is chosen.

The data in tables (1) and (2) show relations for a 500 kc and a 1000 kc intermediate frequency between the shifts of the pulse envelope and cycles. Data for both the 100 kc crystal timers and 50 kc crystal timers are given. Table (1) shows that if a radio frequency of 1950 kc is used, a displacement of one microsecond of corresponding cycles in the remote and local pulses will only give rise to an error of 0.256 microsecond in the pulse envelope.

TABLE I

PULSE ENVELOPE, CYCLE RELATIONS IN A STANDARD LORAN CYCLE-MATCHING SYSTEM
I. F. = 500 kc
R. F. = 1950 kc

Phase Shifter Rotation		Timers with 50 kc Crystals		Timers with 100 kc Crystals	
	Turns	Envelope Shift	Wave Shift	Envelope Shift	Wave Shift
1.	1	20 μs	39 cycles	10 μs	19.5 cycles
2.	1/20	1 μs	1.95 cycles	- - -	- - -
3.	1/10	- - -	- - -	1 μs	1.95 cycles
4.	1/20	1 μs	3.9 μs	- - -	- - -
5.	1/10	- - -	- - -	1 μs	3.9 μs
6.	1/78	.256 μs	1 μs	- - -	- - -
7.	1/39	- - -	- - -	.256 μs	1 μs
8.	1/39	.513 μs	1 cycle	- - -	- - -
9.	2/39	- - -	- - -	.513 μs	1 cycle

TABLE II

PULSE ENVELOPE, CYCLE RELATIONS IN A STANDARD LORAN CYCLE-MATCHING SYSTEM
I. F. = 1000 kc
R. F. = 1950 kc

Phase Shifter Rotation		Timers with 50 kc Crystals		Timers with 100 kc Crystals	
	Turns	Envelope Shift	Wave Shift	Envelope Shift	Wave Shift
1.	1	20 μs	39 cycles	10 μs	19.5 cycles
2.	1/20	1 μs	1.95 cycles	- - -	- - -
3.	1/10	- - -	- - -	1 μs	1.95 cycles
4.	1/20	1 μs	1.95 μs	- - -	- - -
5.	1/10	- - -	- - -	1. μs	1.95 μs
6.	1/39	.513 μs	1. μs	- - -	- - -
7.	2/39	- - -	- - -	.513 μs	1 μs
8.	1/39	.513 μs	1 cycle	- - -	- - -
9.	2/39	- - -	- - -	.513 μs	1 cycle

Thus an error can be more readily detected and a correction applied. The amount of displacement of the pulse envelope due to a cycle displacement of one microsecond will be different for each standard loran frequency. Table (3) shows the displacement of the pulse envelope for a one microsecond displacement of a cycle at all standard loran frequencies.

TABLE III

ENVELOPE SHIFT IN MICROSECONDS FOR A ONE MICROSECOND DISPLACEMENT OF A CYCLE

Loran Frequency	Envelope Shift I. F. 500 kc	Envelope Shift I. F. 1000 kc
1950 kilocycles per second	0.256 microseconds	0.513 microsecond
1900 " "	0.263 "	0.526 "
1850 " "	0.270 "	0.540 "
1750 " "	0.286 "	0.572 "

The direction of movement of the cycles with respect to the pulse envelope depends on the relation of the injection frequency of the cycle-matching receiver, to the radio frequency. If the injection frequency is above the radio frequency, the cycles will appear to move in a direction opposite to that of the pulse envelope. If the injection frequency is below the radio frequency, the cycles and the pulse envelope will move in the same direction, but at different rates.

In a cycle-matching system such as this, only definite increments may be added at the slave station as a coding delay. This is because only at certain intervals will the cycles and pulse envelope be in correct relation with each other, because of the cycles moving with respect to the pulse envelope as the phase shifter is turned. Table 4, below lists the permissible increments of coding delay for standard loran frequencies.

TABLE IV

PERMISSIBLE INCREMENTS OF DELAY

Frequency	Delay Increments Permissible
1950 kilocycles per second	20 microseconds
1900 " " "	10 "
1850 " " "	20 "
1750 " " "	4 "

The permissible delay settings, however, will be different for the odd repetition rates from the even rates. This is because the time intervals between pulses of the odd rates are odd multiples of 50 microseconds. Therefore, on odd rates to keep the pulse-envelope-cycle relation correct the delay must be selected so that the time interval between pulses is a multiple of the permissible increment of delay for the particular frequency being used.

Cycle matching also requires that the pulse shape be accurately controlled so positive identification will be possible. The pulses would have to be matched first by means of their video envelopes and then by the cycles. This would require in the case of a 500 kc intermediate frequency and a 1950 kc r. f. that it be possible to determine an envelope mis-match of the order of one-quarter microsecond. A mis-match of this order can be seen more readily, under ideal conditions, if the unrectified pulse envelope is used on a sweep whose duration is about 75 microseconds. There is some advantage in envelope matching this way rather than by video (rectified) pulses. If the pulse shapes are well controlled, differences in amplitudes of individual cycles can be used to detect a mis-match of a cycle.

EXPERIMENTAL CYCLE-MATCHING EQUIPMENT

The experimental cycle-matching system employs the Loran Timers Model C and Model UE-1 as the frequency standards and timing equipments. The transmitter synchronization pulses supplied by the two timers are used to key very low power pulse generators in which the carrier frequency is derived from the timer crystal oscillators through suitable radio frequency multipliers. The pulse generator outputs consist of low-power loran signals in which the time relation of the r-f cycle and modulation envelope is fixed. These simulated loran r-f pulses are applied to a cycle-matching receiver located in the Model C Timer and to a modified loran receiver-indicator on which the delay readings are taken. The above experimental system simulates an operational cycle-matching loran system, comprising two stations, a master and slave, with a loran receiver-indicator on which time differences can be read. However, since the loran receiver-indicator is located at the same position as the two transmitting stations, the phenomena associated with propagation are completely eliminated (see Figure 1). For simplicity, the experimental cycle-matching system was operated on a frequency of 1800 kc. The pulse recurrence rate was "slow", the specific rate was zero (twenty pulses per second).

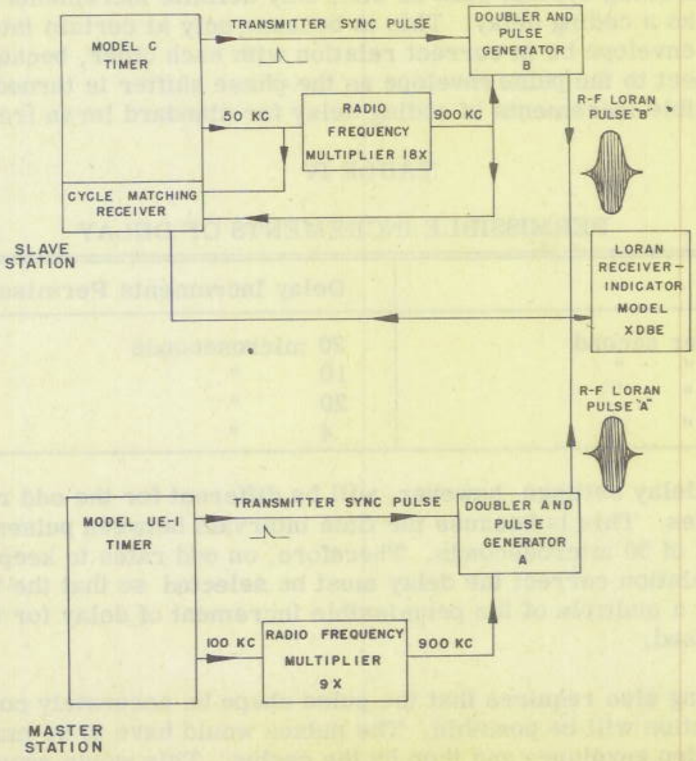


Figure 1 - Experimental Cycle-Matching System

The timers used in the experimental system could have been any model of standard loran timer. The selection of the Model C and Model UE-1 timers was determined by the availability of these two models. The Model C Timer and its associated multiplier and pulse generator served as the slave station. The Model UE-1 Timer and its associated multiplier and pulse generator served as the master station. In addition to the standard function of the timers in a normal loran system, they provide in the cycle-matching system the source for both the radio frequency used in the transmitted pulse, and the injection frequency of the superheterodyne cycle-matching receiver. On the Model C Timer, which contained the cycle-matching receiver, it was necessary to improve the presentation of the fastest sweep, so that the cycles within the pulse would be more easily seen. This was accomplished by decreasing the sweep-time of the fastest sweep from approximately fifty-five microseconds to twenty-four microseconds in length, and installing a variable delay so that the start of both "A" and "B" fast-sweep traces could be delayed in time relative to their respective synchronization pulses by the same amount. Hence, the fast sweep gave an enlarged view and the variable delay enabled an observer to view any portion of the forty-microsecond loran pulse.

The radio frequency multipliers generate a frequency of one-half the carrier frequency from the 50 kc crystal oscillator of the Model C Loran Timer, and from the 100 kc crystal oscillator of the Model UE-1 Loran Timer. In the radio-frequency multipliers submultiples of the 100 kc or 50 kc oscillator frequency can be obtained and combined in a converter with various other frequencies necessary to give one-half of the standard loran frequencies, 1750 kc, 1850 kc, 1900 kc, 1950 kc, plus an additional frequency of 1800 kc (reference 2). †

The Cycle-Matching Pulse Generators produce a radio-frequency pulse in which the phase relation of the carrier frequency and the modulating envelope are fixed. This is accomplished by deriving both the carrier frequency and the modulator keyer pulse from the same crystal controlled oscillator located in the associated loran timer. Figure 2 is a block diagram of an experimental cycle-matching pulse generator. The pulse forming thyratron generates the modulating pulses when triggered by the transmitter synchronizing pulse. The shape of the modulating pulses are determined by the circuit constants of the pulse-forming thyratron and associated artificial line. The one-half

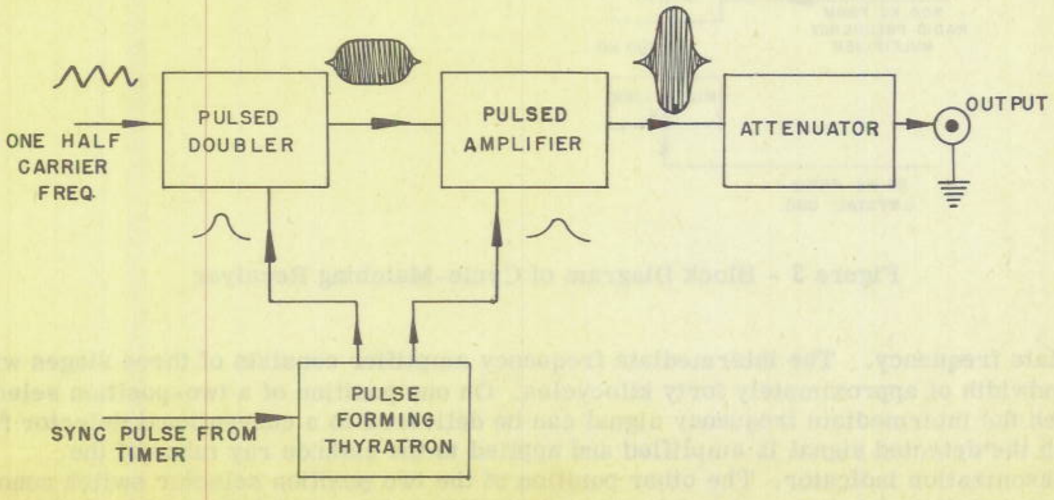


Figure 2 - Block Diagram of Cycle-Matching Pulse Generator

carrier frequency from the radio-frequency multiplier is applied to the pulsed doubler which generates a radio frequency pulse at the carrier frequency when keyed by the modulating pulse. The pulsed amplifier increases the power level and shapes the r-f pulse when keyed by the modulating pulse. Provisions are made so that the shape of the output r-f pulses from the two cycle-matching pulse generators can be made identical.

The experimental cycle-matching receiver is installed in place of the normal loran receiver of the Model C timer. It is a superheterodyne receiver in which the injection frequency for the mixer is derived from the crystal controlled oscillator of the timer, with provisions for obtaining an unrectified output. Figure 3 is a block diagram of the experimental cycle-matching receiver. The radio-frequency amplifier amplifies both the local and remote signals, which, for the example given, are 1800 kc. This signal is mixed with the injection frequency (2800 kc) derived from the timer crystal oscillator. The injection frequency is obtained by mixing the one-half carrier frequency from the radio-frequency multiplier with the tenth harmonic of the 50 kc signal from the timer crystal oscillator. The frequency obtained, in this case 1400 kc, is doubled and amplified to provide the injection frequency (2800 kc). The difference frequency (1000 kc) of the carrier frequency (1800 kc) and the injection frequency (2800 kc) is used, as the intermediate frequency. The intermediate frequency amplifier consists of three stages with a bandwidth of approximately forty kilocycles. On one position of a two-position selector switch the intermediate frequency signal can be delivered to a conventional detector from which the detected signal is amplified and applied to the cathode ray tubes of the synchronization indicator. The other position of the two position selector switch connects the intermediate frequency signal to a tuned amplifier, from which the undetected intermediate frequency signal is applied to the cathode ray tubes of the synchronization

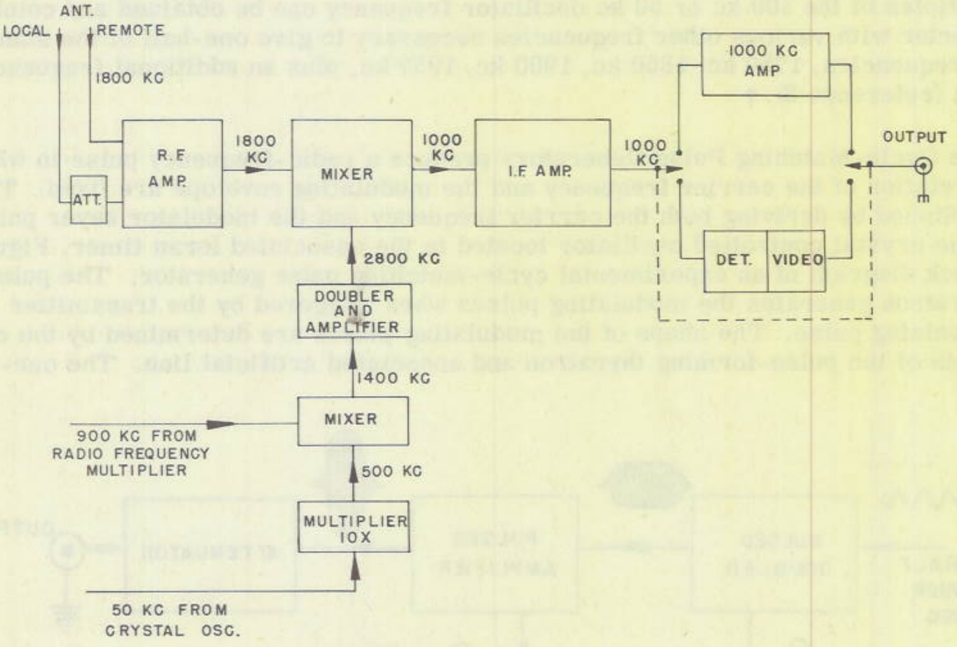


Figure 3 - Block Diagram of Cycle-Matching Receiver

indicator. The appearance of these pulses is shown in Figure 4.

In the experimental cycle-matching system, delay readings were made on a modified Model X-DBE loran receiver-indicator. The modification consisted of installing a vernier dial on the fine delay control knob which enables an observer to read increments of delay directly in tenths of microseconds. Since a crystal for 1800 kc reception on the X-DBE receiver was not available, a DAS-4 receiver which was tuned to receive 1800 kc was substituted for the receiver of the X-DBE receiver-indicator.

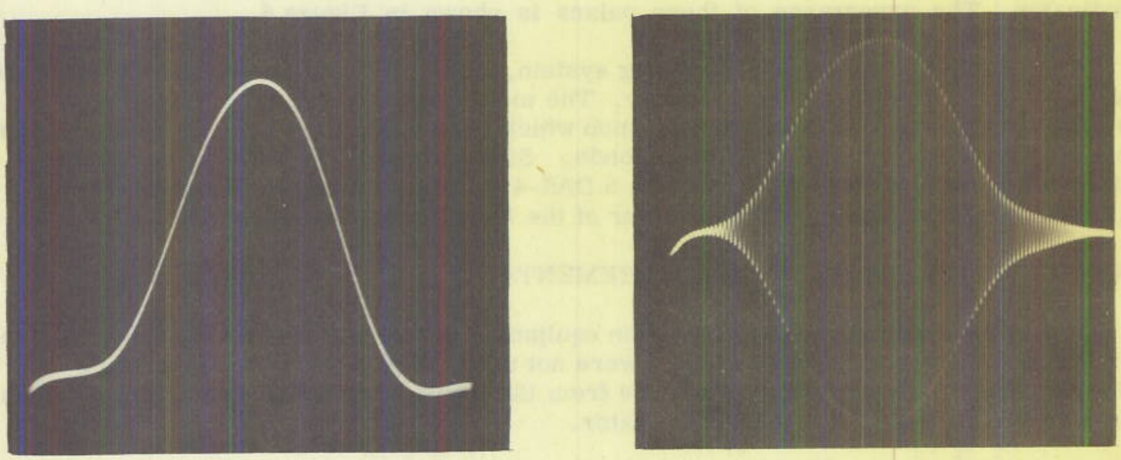
ANALYSIS AND RESULTS OF MEASUREMENTS

Delay readings were made using the equipment previously described, and as shown in Figure 1. Absolute delay readings were not used, only relative readings being desired, hence, all readings were made from the same direction to eliminate blacklash in the gear system of the X-DBE indicator.

In setting up a given delay reading the pulses were matched as closely as possible by means of the pulse envelopes; the presentation was then changed to cycles and a 24-microsecond sweep used. The pulses were then matched cycle for cycle (i. e. by matching the cycle in each pulse that has a corresponding time relation to its respective pulse envelope). This was done by moving the remote pulse with the phase shifter until the cycle patterns coincided. Often the cycle pulses were mis-matched one-half cycle, and under these conditions, it could not be determined in which direction to move the remote pulse. By repeated trials, using extreme care in matching the pulse envelopes, and then switching to cycles the mis-match was less than one-half cycle and the direction to move the remote pulse for a match was apparent. With reasonable care in matching the video pulses, before switching to cycles and a faster sweep for cycle matching, the maximum error in the absolute delay should be plus or minus one cycle. This is equivalent to an error of ± 0.513 microseconds in the pulse envelope for a radio frequency of 1950 kc. (See "Cycle Matching at Standard Loran Frequencies")

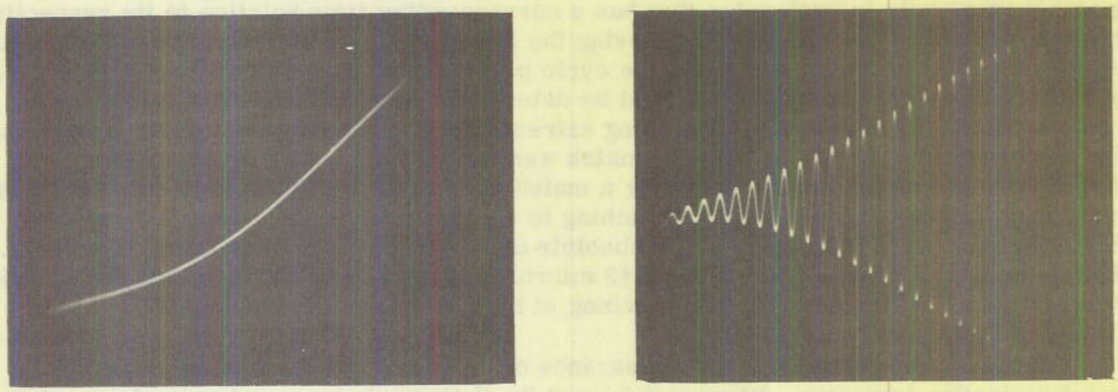
Figures 4 and 5 illustrate the appearance of the pulses on the fast scope of the synchronization indicator. Figures 4 (a) and (b) show the pulse envelope and unrectified pulse on a time base of 120 microseconds. Figure 4 (c) and (d) show the leading edge of the pulse envelope and unrectified pulse on a time base of 24 microseconds. Figure 4 (e) shows a pulse envelope mis-match on the same sweep length as (a). The pattern shown in (d) was similar to that obtained when holding a cycle match. Figure 4 (f) shows cycle pattern on the fast sweep with the pulses slightly mis-matched. Figures 5(a) and (b) show the appearance of the envelope presentation and cycle presentation both under noise conditions. Figure 5 (a) is an exposure of 10 seconds and shows how noise causes all portions of the pulse to fluctuate. Difficulty was experienced in matching the two pulses under these conditions. The method used, however, was to maintain the pulse envelope line at a minimum width. Figure 5(b) is an exposure of 60 seconds and shows that there is little horizontal movement of the vertical lines when the amplitude fluctuates because of noise. Much improvement in the average deviation over the video case was noticed.

A total of 11,000 delay readings was taken. Three groups of readings of 1000 each were taken for pulse envelope and cycle matching. The error of measurement was eliminated by making three similar groups of readings with the slave and master timers controlled by the same crystal. The timers "locked together" in this fashion eliminated operator errors and only instrument and observer errors remained.



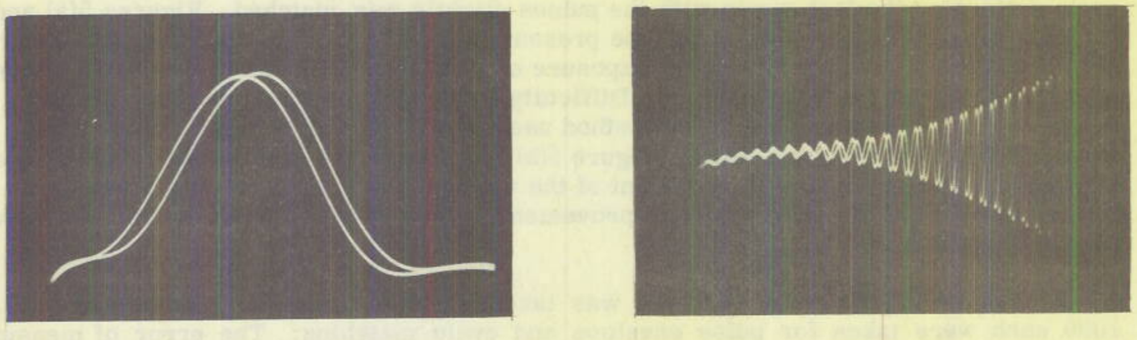
(a) Normal Pulse Envelope
Sweep Time 120 μs

(b) 1 Mc Cycle Pulse
Sweep Time 120 μs



(c) Leading Edge of Pulse Envelope
Sweep Time 24 μs

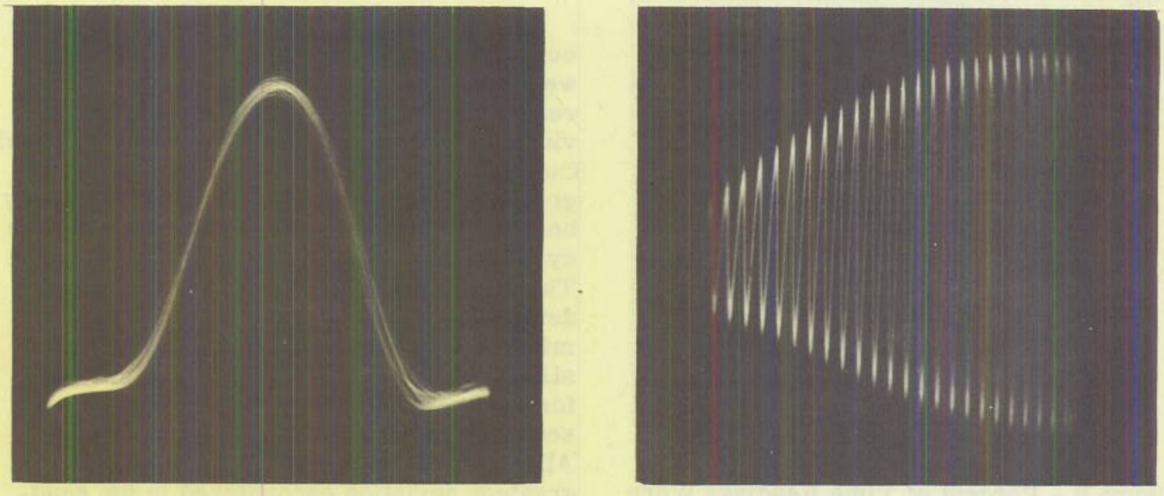
(d) Leading Edge of Cycle Pulse
Sweep Time 24 μs



(e) Pulse Envelopes Slightly Mis-matched
Sweep Time 120 μs

(f) Cycle Pulses Slightly Mis-matched
Sweep Time 24 μs

Figure 4



(a) Normal Pulse Envelopes With Noise Sweep Time 120μs

(b) Portion of the Cycle Pulse With Noise. Sweep Time 24μs

Figure 5

The delay was set at 10,000 microseconds on the slave timer. The operator held the pulses in alignment as closely as possible by means of the phase shifter. The observer, using the X-DBE, made 1000 determinations of the delay reading to the nearest one tenth of a microsecond. These readings were made in groups of 50 each, spaced to make the total elapsed time about three hours. From the data obtained, the average deviation and standard deviation were computed from the arithmetic mean of a group of 1000 readings. This was done for the matching of pulse envelopes, the matching of cycles and deviations with the timers operated from the same crystal. Table 5 shows the results of the above computations for the eleven groups of readings.

TABLE V

DEVIATIONS FOR ALL TESTS

Type of Test	Delay Reading Observer At X-DBE	Average Deviation Microseconds	Standard Deviation Microseconds	Maximum Deviation From Arithmetic Mean Microseconds
Locked #1	HDC	0.13	0.16	0.53
Locked #2	BHW	0.12	0.14	0.34
Locked #3	JWB	0.13	0.15	0.48
Cycle Match #1	HDC	0.14	0.17	0.53
Cycle Match #2	BHW	0.14	0.18	0.62
Cycle Match #3	JWB	0.14	0.19	0.53
Pulse Envelope, Match #1	HDC	0.18	0.21	0.65
Pulse Envelope, Match #2	BHW	0.24	0.30	0.96
Pulse Envelope, Match #3	JWB	0.19	0.23	0.63
Cycle Noise	JWB	0.16	0.19	0.57
Pulse Envelope With Noise	JWB	1.106	1.406	5.77

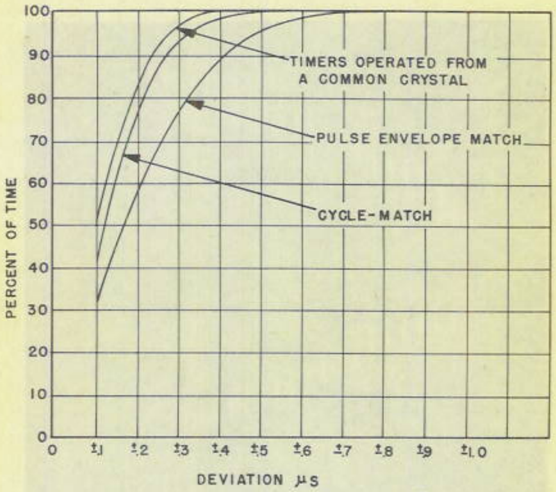


Figure 6 - Percent of Time Readings Were Within a Certain Deviation

The curves in Figure 6 are composite curves for 3000 readings. The deviations were computed over the total spread of readings in a group. The increment of deviation was chosen as one tenth microsecond. On the basis of these deviations, the three groups of readings in the "locked" case may be added together and the same done for the cycle match and pulse envelope match case. The curves show that 80% of the time the deviation was not greater than ± 0.20 microseconds for the "locked" case, only slightly greater or ± 0.22 microseconds for the cycle match case and ± 0.33 microseconds for the pulse envelope match case. All curves have the limit of 100% at the greatest deviation encountered in the readings. Thus, in the case of the pulse envelope match the greatest deviation was one microsecond. The curves in Figure 7 are for cycle match with noise and pulse envelope match with noise. About 1/4 inch of noise was showing on the slow scope of the synchronization indicator. The noise was introduced through the receiver from a noise generator using a multiplier phototube Type 931-A. A decided advantage is apparent in the use of cycle matching for holding a delay reading. With the amount of noise used in these tests, difficulty was experienced in setting up a given delay reading. The curves show that 80% of the time the delay can be held to within ± 0.25 microseconds in the cycle match case which is practically the same as cycle match without noise. The presence of noise does not appreciably increase the difficulty with which an operator can hold the pulses in synchronism by cycle match. It was found that the best portion of the pulse to use was the center when noise was present. At this location noise causes little phase shift in the cycles and variation in amplitude caused by the noise does not cause appreciable horizontal shift in the vertical lines of the cycle pattern. The pulse envelope match noise curve shows that 80% of the time delay can be held within ± 1.75 microseconds.

Each of the five bar graphs, Figures 8, 9, 10, 11 and 12 show the distribution of readings about their mean. Deviations on one side of the mean were taken as plus and those on the other side are given a minus sign. A narrow graph with large numbers of deviations in each increment results from a small average deviation. A wide spread of the readings with fewer totals in each deviation increment is indicative of a larger average deviation. It shows that the delay was held within larger limits than in the case of the narrow graph.

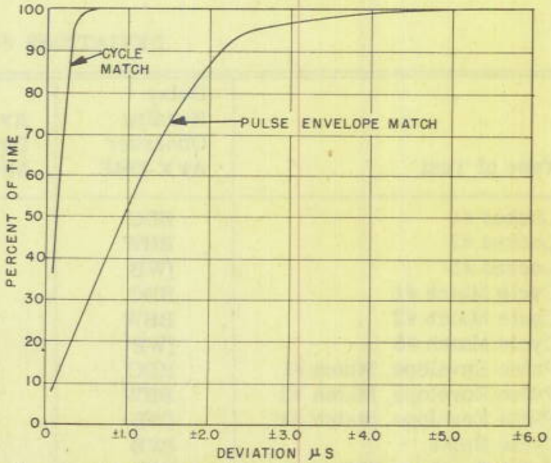


Figure 7 - Percent of Time Readings Were Within a Certain Deviation

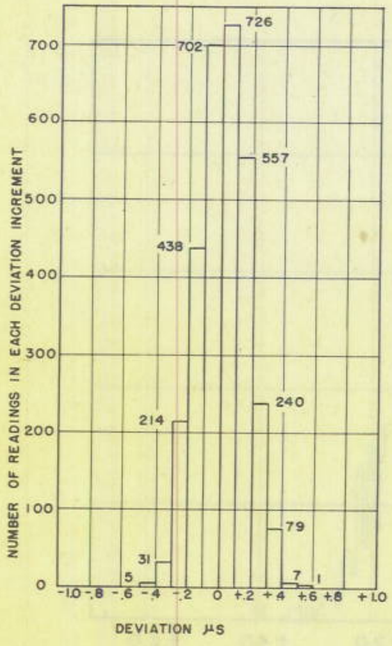


Fig. 8 - Frequency Distribution of Readings for instrument and Observer Error (3000 Readings

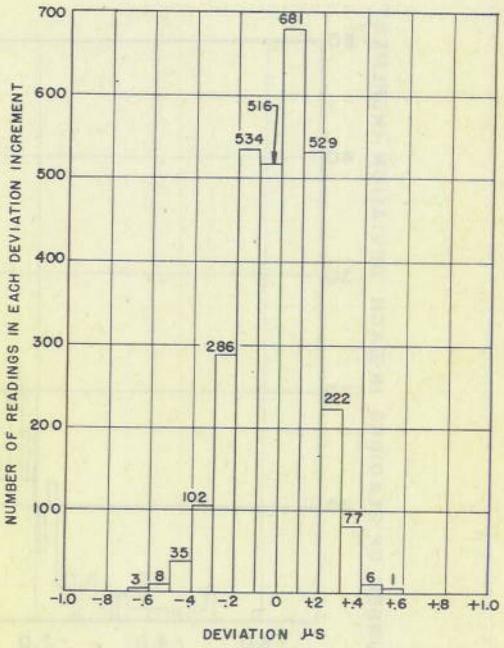


Fig. 9 - Frequency Distribution of Delay Readings Using Cycle-Matching Technique (3000 Readings)

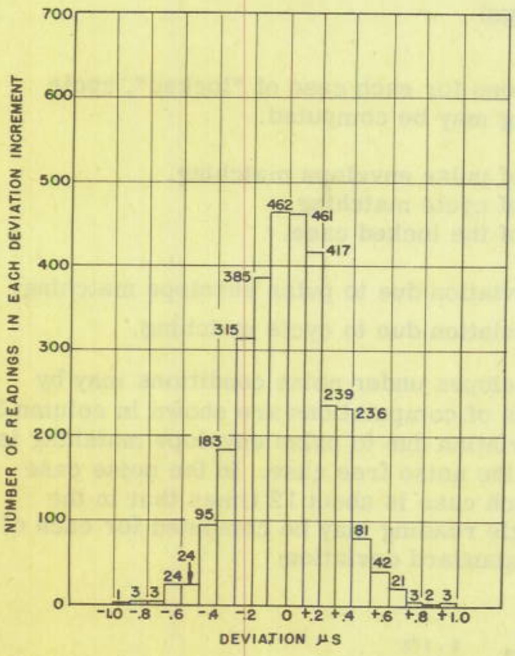


Fig. 10 - Frequency Distribution of Delay Readings Using Pulse Envelope Matching Technique (3000 Readings)

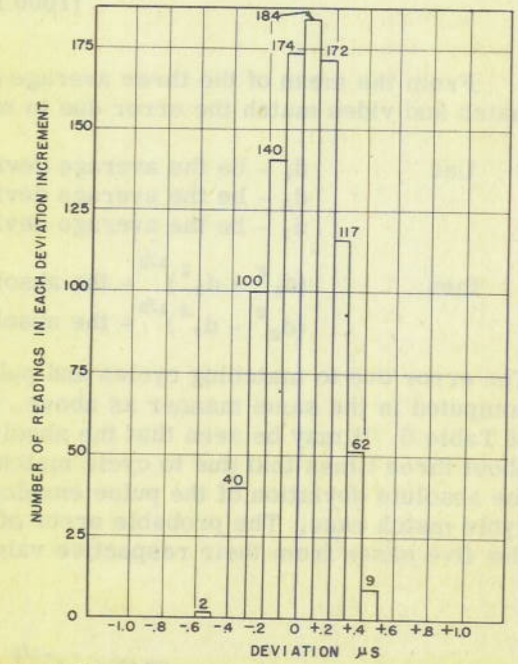


Fig. 11 - Frequency Distribution of Delay Readings With Noise Using Cycle-Matching Technique (1000 Readings)

[redacted]

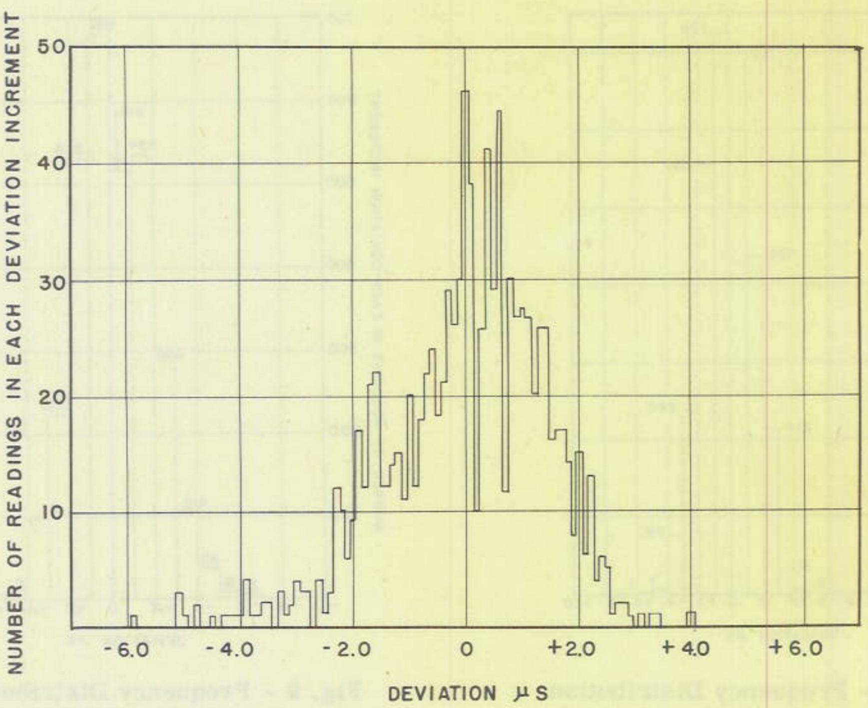


Figure 12 - Frequency Distribution of Delay Readings With Noise Using Pulse Envelope Matching Technique (1000 Readings)

From the mean of the three average deviations for each case of "locked", cycle match and video match the error due to matching may be computed.

Let d_1 - be the average deviation of pulse envelope matching.
d_2 - be the average deviation of cycle matching.
d_3 - be the average deviation of the locked case.

then $(d_1^2 - d_3^2)^{1/2}$ = the absolute deviation due to pulse envelope matching.
$(d_2^2 - d_3^2)^{1/2}$ = the absolute deviation due to cycle matching.

The error due to matching cycles and pulse envelopes under noise conditions may by computed in the same manner as above. Results of computations are shown in column 3 of Table 6. It may be seen that the absolute deviation due to pulse envelope matching is about three times that due to cycle matching in the noise free case. In the noise case the absolute deviation of the pulse envelope match case is about 12 times that in the cycle match case. The probable error of a single reading may be computed for each of the five cases from their respective values of standard deviation:

$$r = .6745\ (n-1)^{-1/2} \left(\sum_{1}^{n} \Delta^2 \right)^{1/2}$$

where r is the probable error of a single reading.

n is the number of readings.
Δ is the deviation of a single reading.

Any one delay reading made will then be the reading (R) plus or minus the probable error.

Or: $R \pm r$ microseconds

The probable error due to cycle matching and pulse envelope matching, after observer error and instrument errors have been taken out, may be computed. This is the absolute probable error. Results are tabulated in column 6 of Table 6. Thus it may be seen that in the noise-free case the probable error of a delay reading made using pulse envelope match is about twice that when cycle match is used. In the noise case, the probable error of a delay reading made using pulse envelope match is about twelve times that when cycle match is used.

TABLE VI

ABSOLUTE DEVIATIONS AND PROBABLE ERROR

Method of Match	Deviation Microseconds	Absolute Deviation Microseconds	Standard Deviation Microseconds	Probable Error Microseconds	Absolute Probable Error Microseconds
Cycle	0.14	0.052	0.18	± 0.120	± 0.063
Pulse envelope	0.20	0.152	0.26	± 0.169	± 0.134
Locked	0.13	- - -	0.15	± 0.101	± - - -
Cycle Noise	0.16	0.093	0.19	± 0.128	± 0.079
Pulse envelope with Noise	1.106	1.102	1.406	± 0.949	± 0.943

CONCLUSIONS

The cycle presentation of a cycle-matching loran system enables an operator to maintain synchronism with less deviation about a mean, than is possible using a pulse envelope presentation. However, with the uncertainties of cycle identification in the experimental cycle matching system where the 1 megacycle intermediate frequency was matched, the full advantages of cycle matching were not realized. The advantages became more pronounced as the noise level increases, (Reference, Table V) and even with the uncertain cycle identification of the present system, at noise levels where the advantage of small deviation exceeds the disadvantages of uncertain cycle identification, great improvement in maintaining synchronism was noted. The primary reason for the improvement in the presence of noise is that in passing the intermediate frequency directly to the indicator, the time constants of the conventional detector and video amplifier circuits are eliminated, allowing the receiver to recover much more rapidly from individual noise pulses or crashes of static.

A system using one megacycle as the intermediate-frequency for matching is not recommended because of the extreme difficulty in matching proper cycles. By using a lower frequency for the intermediate-frequency cycle matching, it is possible that there will be some improvement in cycle identification along with an even greater increase in ability to hold a particular match, since a lower intermediate frequency would provide for larger cycles on the screen of the "fast scope". It would make their observation easier and the differences in amplitudes easier to determine.

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