USE OF LORAN C
FOR INTERCONTINENTAL SURVEYING (*)

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Introduction

Loran is a radio position fixing system in which a mobile receiver measures the difference in time-of-arrival of pulse signals from a number of synchronized transmitting stations. A pair of Loran transmitters produces a family of hyperbolic lines of position. A second pair of transmitters generating intersecting lines will produce a fix. Standard Loran, known as Loran A, operating at about 2 megacycles, has been in use for approximately 20 years.

In the past few years, the Loran C system, operating at a frequency of 100 kc/s has come into increasingly widespread use. This system obtains longer range and higher accuracy than Loran A by virtue of its use of low radio frequencies and instrumentation measuring the phase of the 100 kc/s carrier frequency. Ground wave propagation at 100 kc/s is quite stable and predictable. Measurements of ground wave signals have been made at distances over 2 000 miles.

Because of the extremely stable nature of the ground wave propagation, it was felt that Loran C could be a very useful tool for the measurement of long distances, especially over water where propagation conditions are quite constant and where other means of surveying are difficult. Accordingly, a proposal was made to the Air Force Cambridge Research Center, which resulted in a contract in July 1959 for a study program to determine the feasibility of just such a system.

(*) *IHB Note.* — A Supplementary Paper to S.P. 39 containing an article describing Loran C is in the press.

East Coast Chain

The first Loran C chain had been set up in 1957 on the East Coast of the United States at locations shown in figure 1. This chain had been calibrated by use of mobile monitor receivers and considerable data had also been taken by utilizing monitors on the baseline extensions of the two slave stations in Florida and Massachusetts. These stations are now in continuous operation as a part of the Loran C facility being operated on a world-wide basis by the U.S. Coast Guard. However, the data available from the East Coast chain presented an excellent opportunity to determine the accuracy with which long distances could be measured utilizing Loran C signals. As can be seen in the figure, the short path between the master station and the X slave station at Jupiter, Florida, is entirely over water. The path between the master and the Y slave at Martha's Vineyard contains approximately 30 % land. However, the path between the two slave stations, which is 1 143 miles long is entirely a water path except for the land in the immediate vicinity of the transmitters.

The presence of the monitor receivers was especially important to the experiment since time difference readings at the stations themselves are influenced by the near field effects of the transmitters. It is necessary to locate a monitor receiver several miles from the transmitter in order to obtain accurate time difference measurements. The correct readings at the master station were obtained during the chain calibration by use of a mobile monitor receiver making measurements along each baseline extension.

During the period for which data were available, operation was not continuous; and in particular, not all monitors were operated simultaneously. For this reason, selected days during the period from January to May 1958 were chosen as representative of normal operation conditions. The latitude and longitude of each of the transmitters and receivers were obtained from survey data and the geodetic distance was calculated according to standard formulae.

Distance Calculation

The radio distance, which is the distance obtained by combining the time difference readings at the various monitors, was obtained from the following formula :

$$D_{EM} = \frac{C}{n} (TT_{EM} - t_c)$$

where

D_{EM} = electronically measured distance
C = velocity of light = 299 792.5 ± .3 m/s
n = atmospheric refractive index
TT_{EM} = electrically measured travel time
t_c = secondary factor

The secondary factor t_c is a phase correction, calculated here in microseconds, which is a function of the distance from the transmitter and also varies with frequency and earth conductivity. Formulae for deriving the values used in the calculations were obtained from National Bureau of Standards Circular 573 " Phase of the Low Radio Frequency Groundwave ".

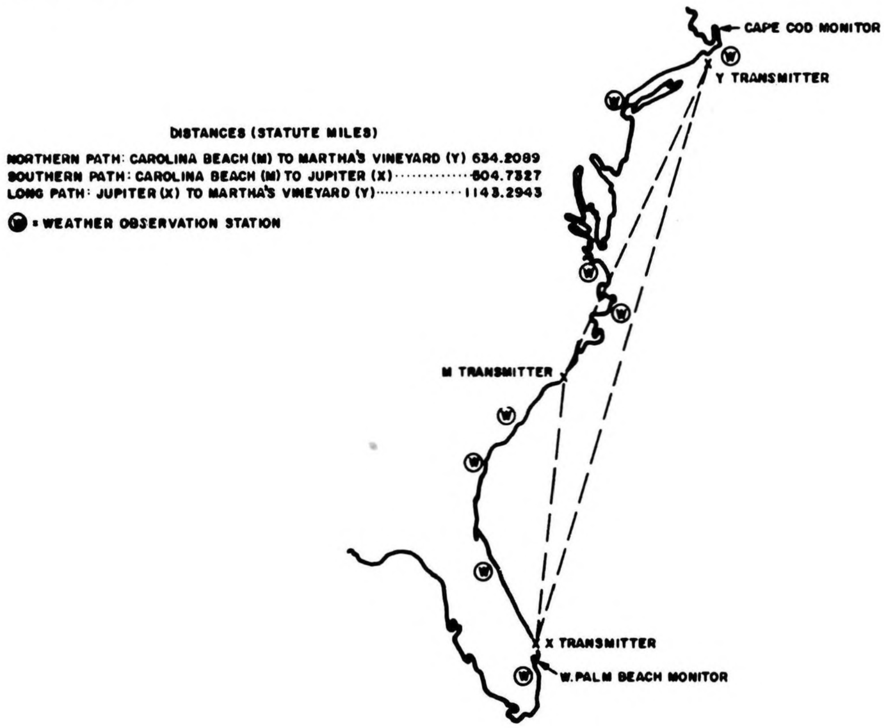


FIGURE 1
East Coast Loran C chain and weather stations.

Values of n, the index of refraction, were calculated for various points along the paths from meterological data taken at points indicated by W in figure 1. The refractivity data were used not only in the calculation of n but also as one of the factors in calculating t_c. Figure 2 shows the manner in which the secondary factor varies with refractivity for the three paths calculated in this study.

In order to evaluate the accuracy of the distances calculated by conventional means, an estimate was obtained from the Coast and Geodetic Survey of the probable accuracy of the survey distance. This accuracy was estimated at approximately one part in 75 000 or an error of 25 metres at a distance 1 800 kilometres, the length of the longest path involved in this study.

Study Results

The most important of the results obtained are shown in figure 3. This shows the variation in the measured one-way travel time on the long path between the two slave stations in terms of microseconds and shows

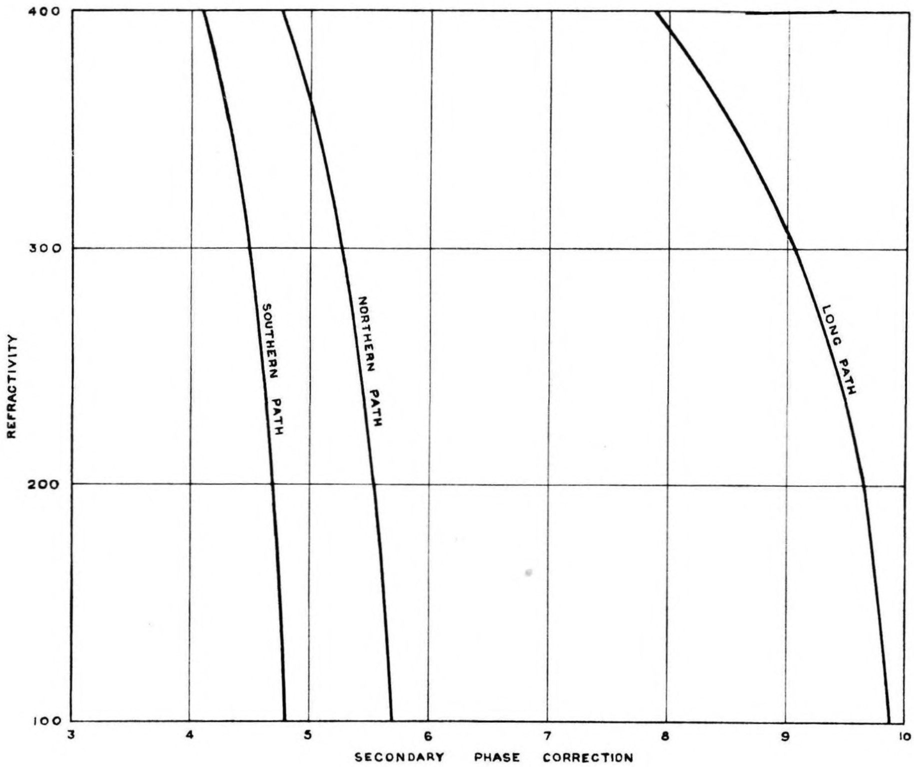


FIGURE 2
Variations of secondary phase correction with refractivity for different paths.

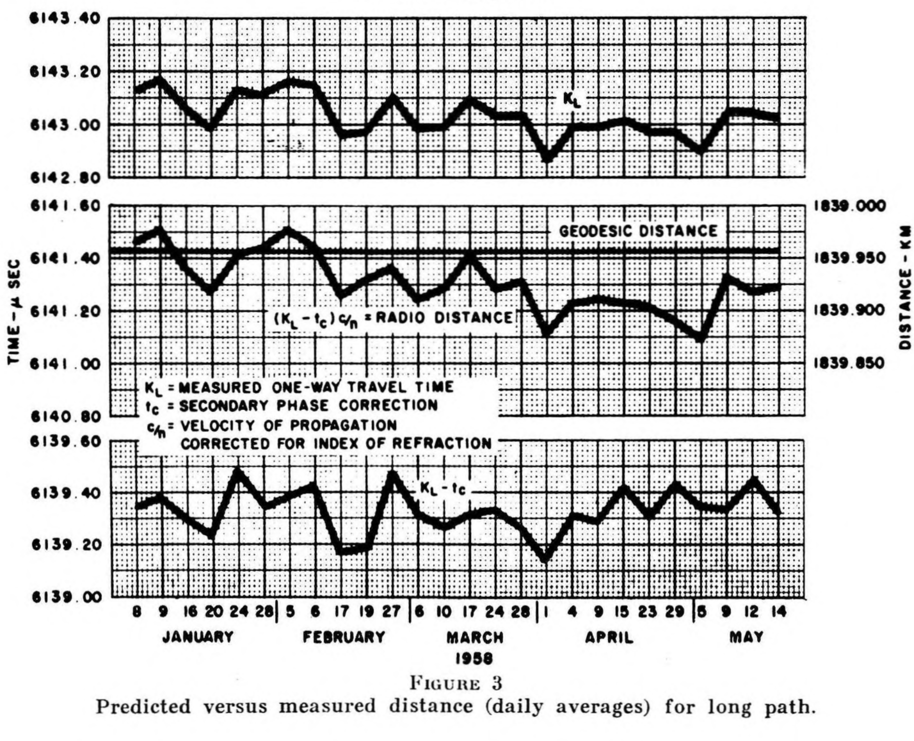


FIGURE 3
Predicted versus measured distance (daily averages) for long path.

the effects of correction for secondary phase factor and for the index of refraction. This final corrected travel time is converted to distance in kilometres as indicated at the scale on the right. This may be compared with the distance as calculated from the geodetic positions of the two stations at the end of the paths. As can be seen, the average difference between the radio distance and the geodetic distance is of the order of 20 metres.

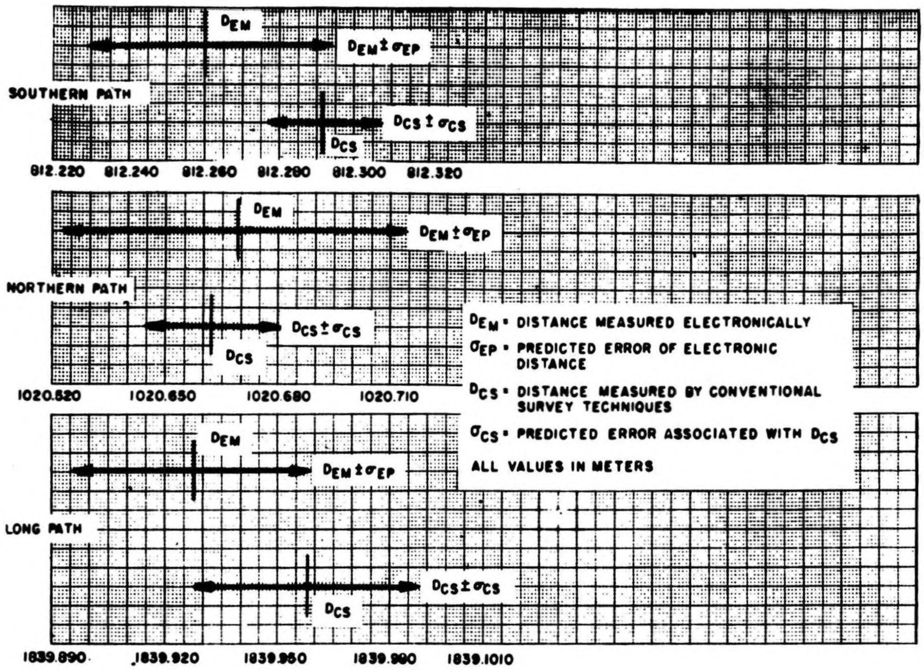
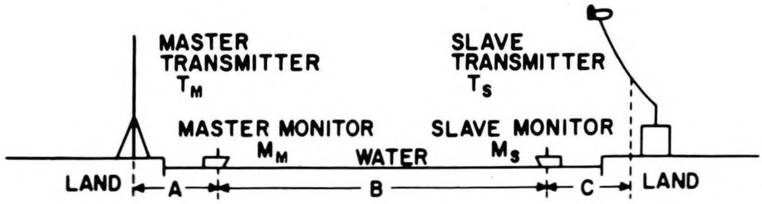


FIGURE 4
Predicted and measured distances and associated errors.

In order to present graphically the difference between the electrically measured and the surveyed distances along with the probable errors of both sets of measurements, the data were prepared in the form of figure 4. Here the electrically measured distance and the survey distance for each of the three paths is presented with the standard deviation of each of the types of measurements indicated by the arrow. The error in the conventional surveying is again assumed to be one part in 75 000. As can be seen, the standard deviation combined with the actual measurements in each case produces a substantial overlay between the electronic and conventional surveying methods.

Survey System

Actual implementation of this survey technique involves the measurement of the baseline between two Loran C transmitters by means of two monitor receivers which could be located in the boats a short distance off



VELOCITY OF PROPAGATION	V	
MASTER TRANSMITS AT TIME ZERO	O	
SIGNAL ARRIVES AT MASTER MONITOR AT	A/V	(1)
SIGNAL ARRIVES AT SLAVE MONITOR AT	(A+B)/V	(2)
SIGNAL ARRIVES AT SLAVE TRANSMITTER AT	(A+B+C)/V	(3)
SLAVE TRANSMITTER CODING DELAY	σ	(4)
SLAVE TRANSMITTER TRANSMITS AT	$(A+B+C)/V+\sigma$	(5)
SLAVE SIGNAL ARRIVES AT SLAVE MONITOR AT	$(A+B+C)/V+\sigma+C/V$	(6)
SLAVE SIGNAL ARRIVES AT MASTER MONITOR AT	$(A+B+C)/V+\sigma+(C+B)/V$	(7)

MASTER MONITOR READING $= (7)-(1)$

$= (A+B+C)/V+\sigma+(C+B)/V-A/V$

$= 2(B+C)/V+\sigma$

SLAVE MONITOR READING $= (6)-(2)$

$= (A+B+C)/V+\sigma+C/V-(A+B)/V$

$= 2C/V+\sigma$

DIFFERENCE OF MASTER MONITOR AND SLAVE MONITOR READING

$= 2(B+C)/V+\sigma-2C/V-\sigma$

$= 2B/V$

INDEPENDENT OF A, C, OR σ

FIGURE 5
Transmitter and monitor arrangement.

the shore. Figure 5 shows diagrammatically such an arrangement. The two monitor receivers each measure the difference in time-of-arrival of the signals from the master and from the slave. The analysis below the diagram demonstrates that the difference between the two time difference readings at the two monitors is an accurate measure of the time of travel of the signal between the two monitors independent of variations at the transmitters or the relationship of the monitors to the transmitters themselves. Thus, in order to establish the distance between the two land masses, it is merely necessary to obtain accurately the position of each boat relative to its respective land mass which can be done with sufficient precision by radar. It can also be demonstrated that the monitor receivers need be only approximately along the baseline between the two transmitters and that any minor deviations from this position have an insignificant effect on the distance measurement.

Using this technique for distance measurement, many of the errors which were present in the East Coast Loran C system which was analyzed are no longer of importance.

The following table shows the errors to be expected in a typical Loran C survey system :

Source of fixed errors :

Calculation of t_c	$= \pm .03$ μs (water path)
	$= \pm .07$ μs (part-land path)
Uncertainty of c	$= 299\ 792.5 \pm .3$ km/sec

Source of random errors :

Based on data from Loran C system during a monitoring period of approximately five days.

Standard deviation (metres)

Distance	Fixed	Random	RSS total	Accuracy (1 part per —)
500 n.m.	9.02	4.3	9.99	80 080
1 000 n.m.	9.17	14.1	16.82	95 124
1 500 n.m.	9.22	26.0	27.59	86 988

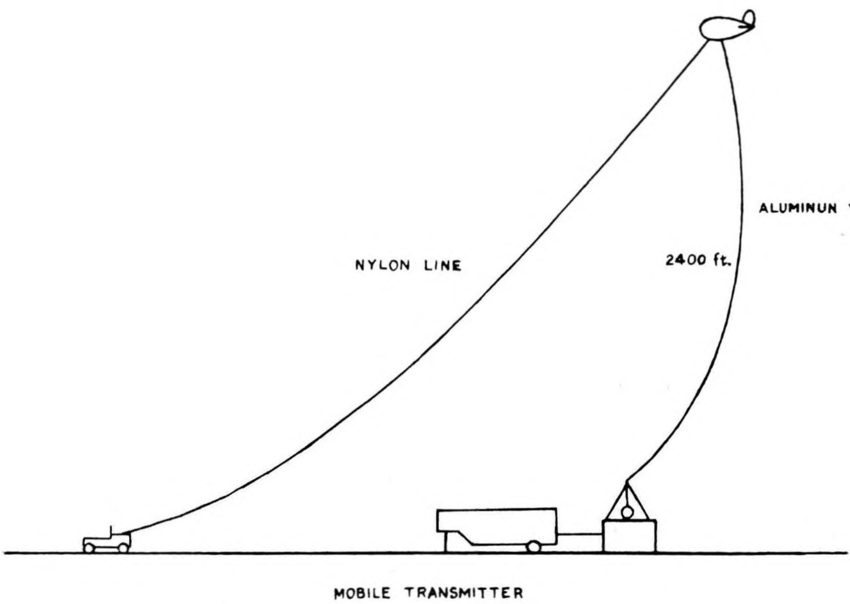


FIGURE 6

Proposed balloon-supported antenna system.

Figure 6 shows one Loran C transmitter using a balloon-supported antenna. This is actually a very practical type of antenna for a portable transmitter used for survey purposes. Because of the receiver-difference technique used, the precise position of the transmitter does not enter into the distance determination, therefore a balloon-supported vertical wire becomes a very efficient antenna.

A total of five Loran C chains are now being operated by the U.S. Coast Guard in both the Atlantic and Pacific Oceans and the Mediterranean Sea. By utilizing any of these stations and one portable station, over-water distances could be measured as indicated in figure 7 to approximately one part in 90 000. In addition, paths which contain some land could be measured to a lesser accuracy estimated at approximately one part in 40 000.

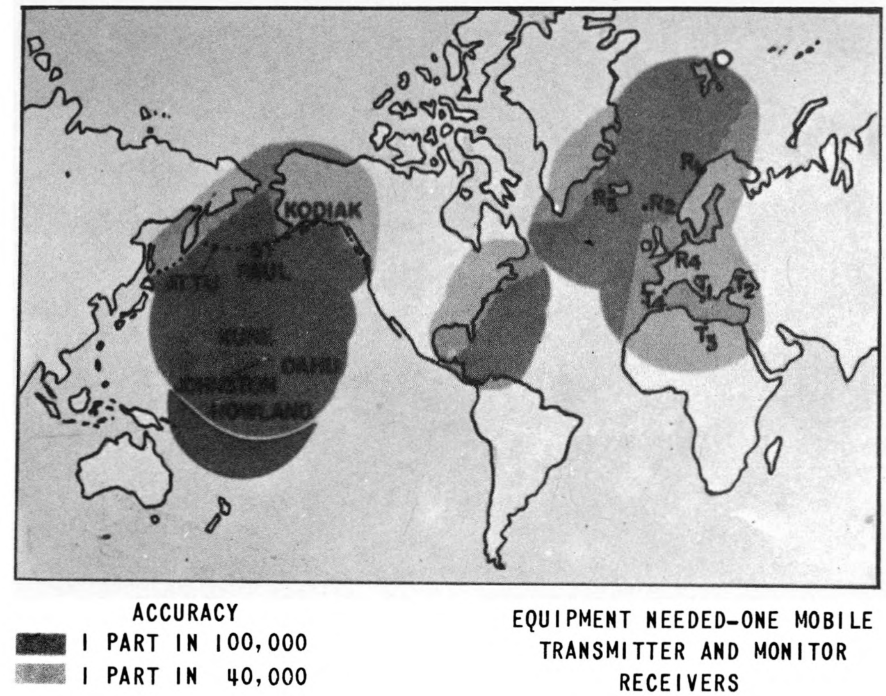


FIGURE 7
Survey coverage area based on 1 500-mile range over sea water.

Conclusions

The analysis of field data indicates that, using the special technique described, overwater distances of up to 1 500 miles can be measured with an accuracy of one part in 90 000. All the necessary equipment already exists, although repackaging of the transmitter would be required for portable use. The cost of performing the actual survey work would be modest, compared to a system such as Hiran, or the uncertain launching of a satellite.