GROUND EFFECTS ON LORAN-C SIGNALS

D. C. Pearce and J. W. Walker
Communications/Automatic Data Processing Laboratory
U. S. Army Electronics Command

ABSTRACT

In conjunction with the test and evaluation of the position fixing capabilities of the Army Manpack Loran Receiver AN/PSN-6, an extensive series of time difference and signal amplitude measurements were made within a 100 km map grid square encompassing Fort Monmouth, New Jersey. The test location is within the coverage area of the East Coast Loran-C Chain. The data were used to develop a simple "smooth-earth" model for the test area as well as to estimate the magnitude and distributions of deviations from this model. Local propagation processes associated with topographic features and the grid of overhead wires in the test area are shown to contribute to the deviations from the model.

INTRODUCTION

As part of a broad program to develop a capability for navigation and position fixing, the Army is in the process of developing a manpack loran receiver. The position fixing function of the receiver is to provide a real time display of either the loran time difference coordinates or the geodetic coordinates of the receiver position. This conversion between the time difference and geodetic coordinate systems is accomplished by a small computer within the receiver. The research described here was designed to provide a data base for development of simple conversion algorithms as well as to provide an error budget for the resulting conversion. Since a fundamental variable of a loran system is the propagation time of the 100 kHz signal and since the manpack loran receiver is designed to operate on the ground, the present research was planned to provide information on ground wave propagation at the surface of the earth. These propagation results are the subject of this paper.

BACKGROUND

The fundamental equation describing the functional relationship between a loran time difference and the loran chain parameters is

$$TD(P) = [(D_s - D_m)/C] + ED, \quad (1)$$

where TD(P) is the loran time difference at a field point P, D_s is the great circle distance from the slave transmitter to the point P, D_m is the great circle distance from the master transmitter to the point P, C is the propagation velocity of the loran signal, and ED is the emission delay, that is the sum of the propagation time from the master to the slave transmitter and the coding delay introduced at the slave station. [See Footnote (a).]

The non-constant propagation velocity, which varies with the density and amplitude of terrain features and the electrical properties of the overland path, severely limits the utility of Eq. (1) for time difference estimation. On the other hand, the ground wave propagation velocity over sea water is a well-known quantity, so Eq. (1) is very useful for this application. A complete knowledge of the propagation velocity for all propagation paths is necessary for rigorous use of Eq. (1). This procedure requires an extremely large volume of data and clearly is not practical for a manpack loran receiver. This fact furnished the impetus for the development of simplified coordinate conversion algorithms. In essence, the approach was to develop a simple local conversion model based on calibration and to investigate the accuracy characteristics of that model. The reader is referred to the work of Johler [1] and to the references cited therein for details on the complete treatment of overland loran propagation.

EXPERIMENTAL PROCEDURE

The test area in New Jersey is the 100 km square, 18T WV of the Universal Transverse Mercator Map System. A specially equipped four-wheel drive mobile unit was used during data acquisition. Present instrumentation includes 2 military loran receivers, a timing receiver system with rubidium standard, and ancillary items including printers, oscilloscopes, and power supplies. The military receivers used roof-mounted whip antennas whereas the timing receiver used a rotatable roof-mounted loop antenna.

The calibration procedure is relatively simple, namely to obtain time difference readings at sites of known geodetic control. To obtain estimates of loran receiver performance, approximately 100 time difference measurements were made with each receiver at each site. These measured values were then averaged to provide a time difference for each site. To eliminate separate site surveys, easily identifiable topographic locations, such as road intersections, were used for geodetic control. Coordinates of all sites were determined from 7.5 minute USGS topographic maps. Criteria for site selection were positive identification, freedom from strong electromagnetic scatterers, and accessibility with the mobile unit. In general, the absence of power lines was the most difficult criterion to meet. Several of the sites were at geodetic bench marks which provided a higher order geodetic control.

The distribution of calibration sites is shown in Fig. 1. The numbers shown in this figure are primarily for site identification purposes, but are also related to the time of calibration. Data at sites identified with numbers less than 1000 were obtained in December 1972, whereas those with identifiers greater than 1000 were obtained in July 1973. This latter study was designed to give an increased calibration density within a 60 km square located in the SE corner of the primary test area. In addition, the absence of nearby power lines was of extreme importance. It is estimated that for these locations, there were no wires within one kilometer of the site. For the December 1972 measurements there were no wires within 300 meters of a site. This consideration of the proximity of overhead wires led to the classification of first and second order TD data, as indicated in Fig. 1.

In October 1973, the timing receiver was used to obtain field strength information at the sites with identifiers less than 1000. Time difference measurements were also obtained to check the repeatability of earlier measurements.

A study of the absolute phase variations of the Loran-C transmissions was initiated in October 1974. The sites for a ray path to the SS7-Y, Nantucket transmitter are designated as phase track points in Fig. 1. All measurements were made relative to the reference point 1480 in Fig. 1. This point is approximately 1 km from the coast. The other sites are at approximately 10 km intervals along the ray path. The experimental procedure was to initialize at the reference point, make phase measurements at other sites, and then close the traverse at the reference site. Each

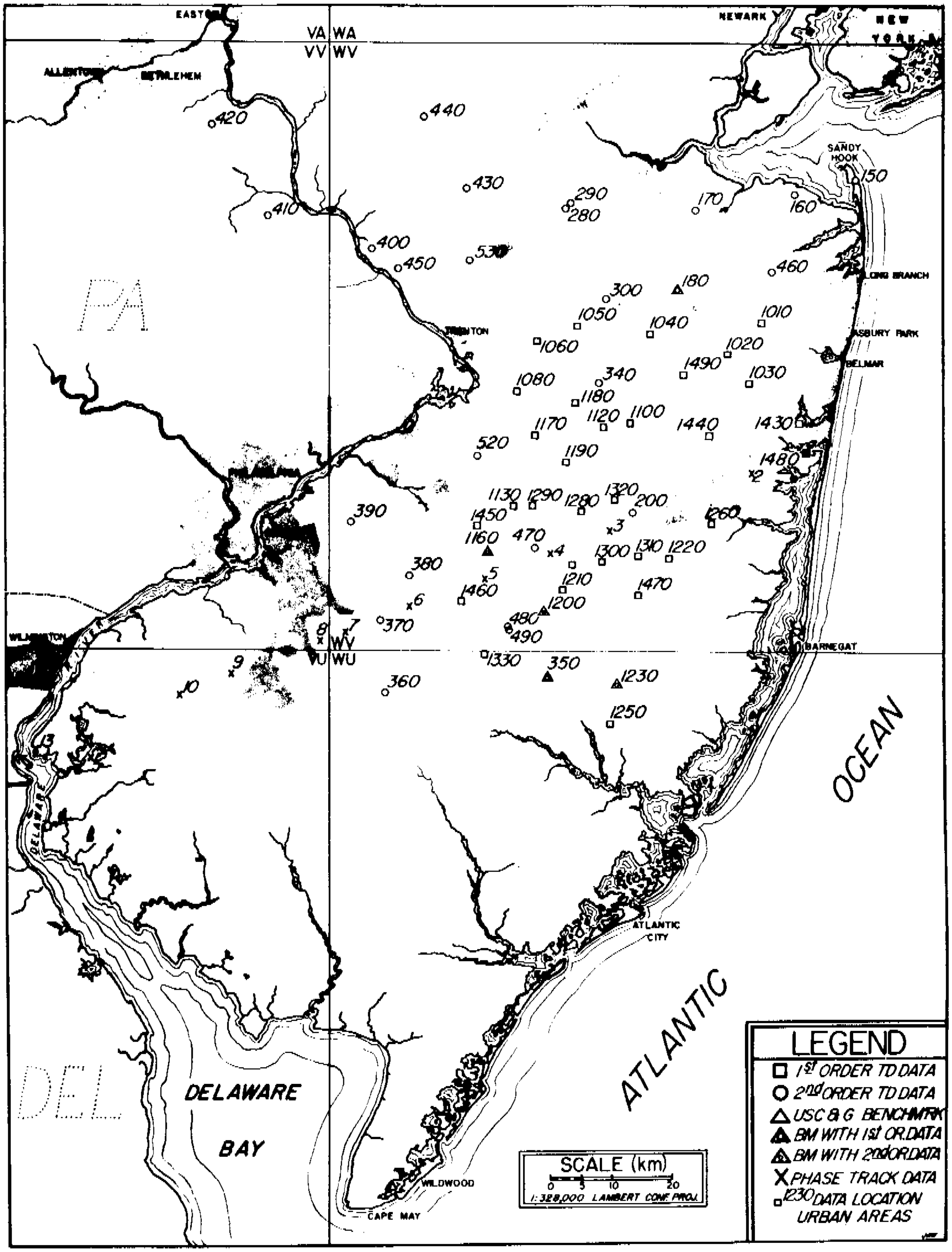

Fig. 1. Map of New Jersey Showing Locations of Loran-C Time Difference and Phase Data Measurements.

series of measurements required from 6 to 8 hours. Closing the traverse at the reference site provided an estimate of the frequency offset of the rubidium standard.

The test area is a segment of the coastal plain which is essentially devoid of pronounced terrain features and conductivity discontinuities. Thus no significant perturbations of the loran signals were expected from these sources.

ANALYTICAL PROCEDURE

The model adopted for data analysis is a modification of Eq. (1). The underlying assumption for this model is that for modest coverage areas, a constant overland propagation velocity will provide a useful approximation. The equation is:

$$TD(P) = (ED + \alpha) + \beta(D_s - D_m) + \varepsilon(\theta_s, \theta_m). \qquad (2)$$

In this expression, α and β are arbitrary parameters to be determined by least squares analysis of the measured data. The correction function, $\varepsilon(\theta_s,\theta_m)$, is to account for sea water paths at a bearing angle θ from the slave and master transmitters to the field point. This function is included to account for the significant difference between ground wave propagation velocity over land and over sea water. The parameter α can be interpreted as an average time difference offset characteristic of the test area. The parameter β can be interpreted as the reciprocal of the local propagation velocity. However, in view of the simplicity of the model and the statistical method of analysis, strict physical interpretation of these parameters should be approached with caution. [See Footnote (b).]

For data processing, the variables D_s and D_m were calculated using the method of Sodano and Robinson [2] for the Clarke 1866 spheroid [3].

The correction $\varepsilon(\theta_s,\theta_m)$ was constructed from tabulated functions of the sea water path length as a function of bearing angle from the Nantucket and Carolina Beach transmitters. The sea water path functions were prepared from maps in increments of 5° in the bearing angle. The path length for intermediate bearing angles was determined by linear interpolation. The sea water path length functions are shown in Figs. 2 and 3 for the Carolina Beach and

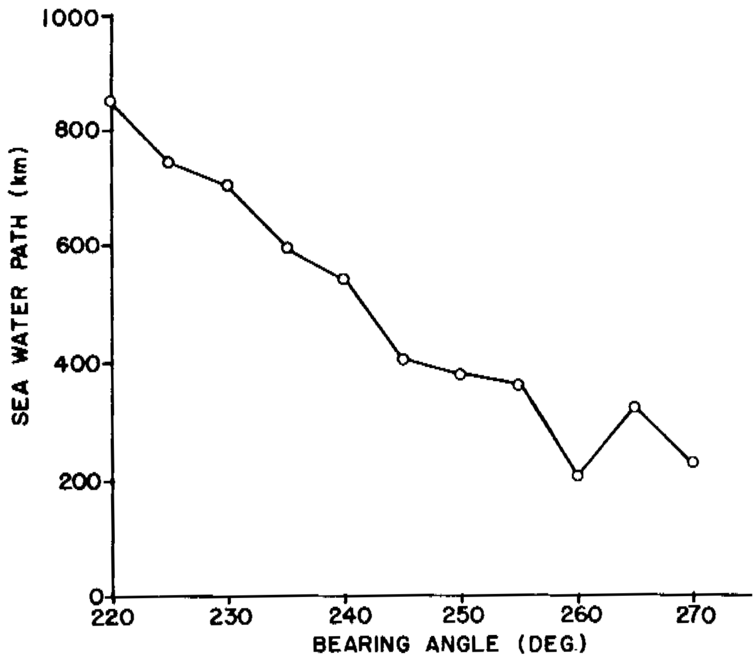

Fig. 2. SS7-Y (Nantucket) Sea Water Path vs. Bearing Angle.

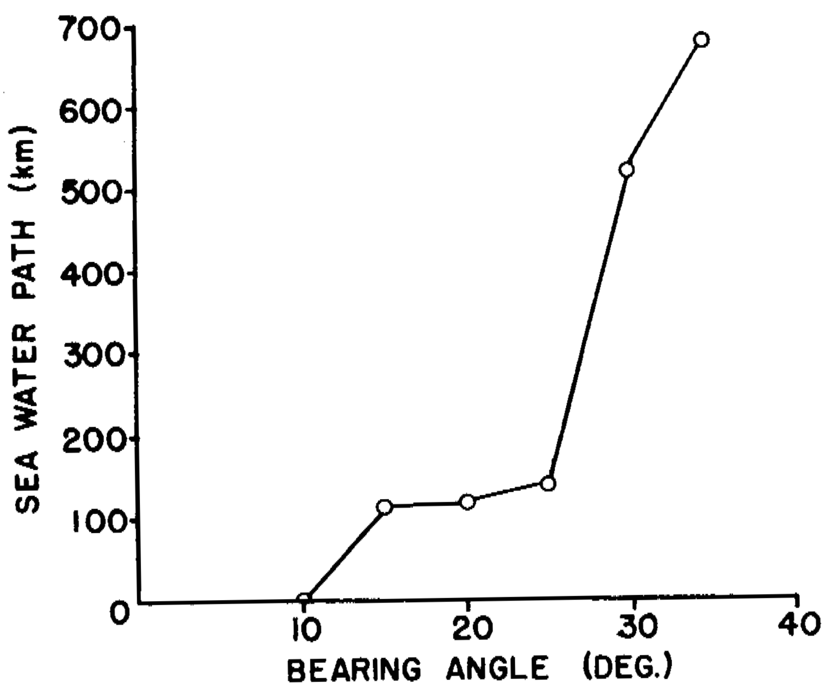

Fig. 3. Master (Carolina Beach) SeaWaterPath vs. Bearing Angle.

Nantucket transmissions. In view of the simple interpolation procedure, the error associated with path length determination will be greatest for bearing angles greater than 25° for the Carolina Beach transmission. For this reason, all points with Carolina Beach bearing angles greater than 25° were not considered in the data analysis. This selection process left 61 calibration sites within the 100 km square.

The correction function is

$$\varepsilon(\theta_s,\theta_m) = k[L_s(\theta_s) - L_m(\theta_m)] \ . \qquad (3)$$

In this expression, $L_s(\theta_s)$ is the sea water path length at a bearing angle θ_s from the slave transmitter and $L_m(\theta_m)$ is the sea water path length at a bearing angle θ_m from the master transmitter, $k = [(1/C_\ell) - (1/C_s)]$ where C_ℓ is the ground wave propagation velocity over land and C_s is the ground wave propagation velocity over sea water. The values used for these constants are: $(1/C_\ell) = 3.3416$ μs/km and $(1/C_s) = 3.3384$ μs/km. Thus the constant k has the value 0.0032 μs/km. The value of C_s was obtained from the tables of Johler and Berry [4]. The value of C_ℓ was estimated from calibration of a geologically similar area in North Carolina where no sea water correction was required.

ANALYTICAL RESULTS

As discussed previously, the data processing was designed to give the parameters α and β for the Nantucket and Dana slave configurations by the method of least squares. To evaluate the effect of coverage area size, the data were treated in two sets. One set included the total of 61 points. The second set included the points within a 60 km square in the SE corner of the 100 km square.

The analytical results are shown in Tables I and II. Also shown are the RMS deviations of the least squares fit for each data set.

TABLE I. STATISTICAL PARAMETERS FOR 100 km SQUARE (61 Data Points)

Transmission Pair	α (μs)	β (μs/km)	RMS Deviation for Set
SS7-Y	0.85	3.346	0.33
SS7-Z	-0.19	3.339	0.33

TABLE II. STATISTICAL PARAMETERS FOR 60 km SQUARE (30 Data Points)

Transmission Pair	α (μs)	β (μs/km)	RMS Deviation for Set
SS7-Y	0.74	3.346	0.22
SS7-Z	-4.11	3.349	0.25

An estimate of the experimental uncertainties was obtained by statistical analysis of the data acquired at each site. This procedure yielded an average value of 0.15 μs attributable to instrumental jitter. In addition, it has been estimated that the use of topographic maps introduces a location uncertainty of the order of 20 meters. For the test area, this corresponds to a time difference error of about 0.1 μs. Therefore, experimental processes are estimated to contribute an uncertainty of the order of 0.18 μs.

The distribution of the magnitude of the time difference deviations is shown in Figs. 4 and 5 for the Nantucket-Carolina Beach (SS7-Y) and the Dana-Carolina Beach (SS7-Z) configurations, respectively. The solid curves are the normal distributions corresponding to the standard deviations calculated for each slave configuration. The areal distribution of the time difference deviations for each slave configuration is shown in Figs. 6 and 7.

The results of the field strength study of October 1973 are shown in the contour plots of Figs. 8 and 9 for the Nantucket and Dana transmissions, respectively. The contour

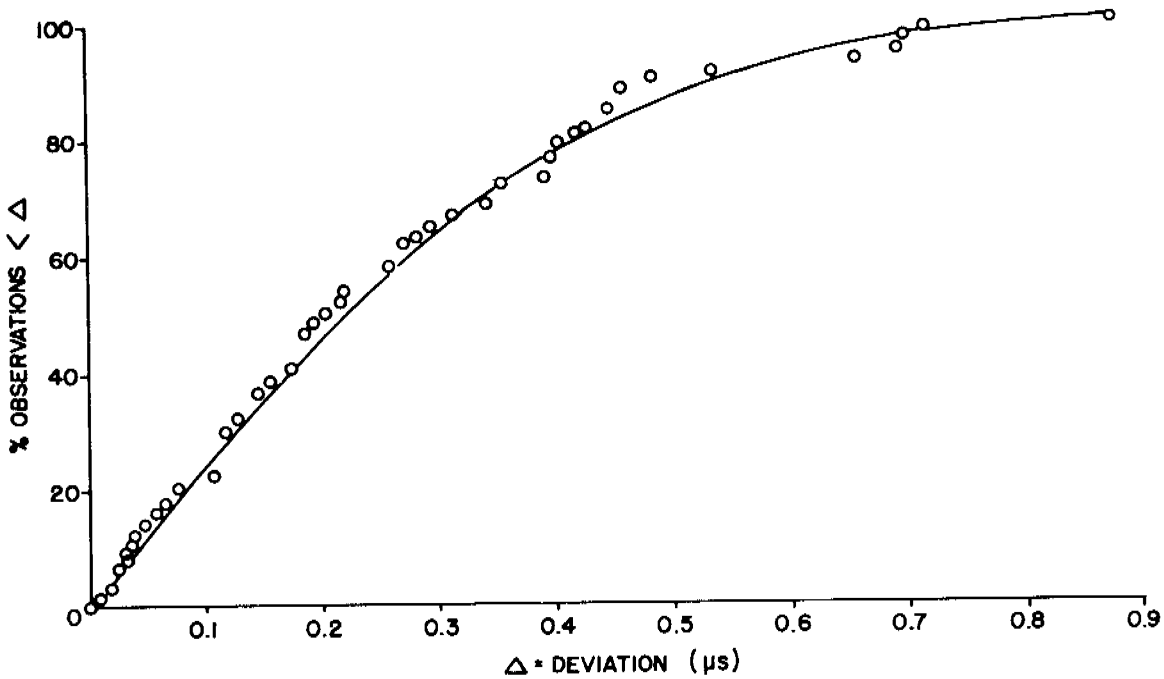

Fig. 4. SS7-Y Time Difference Deviation Magnitude Distribution.

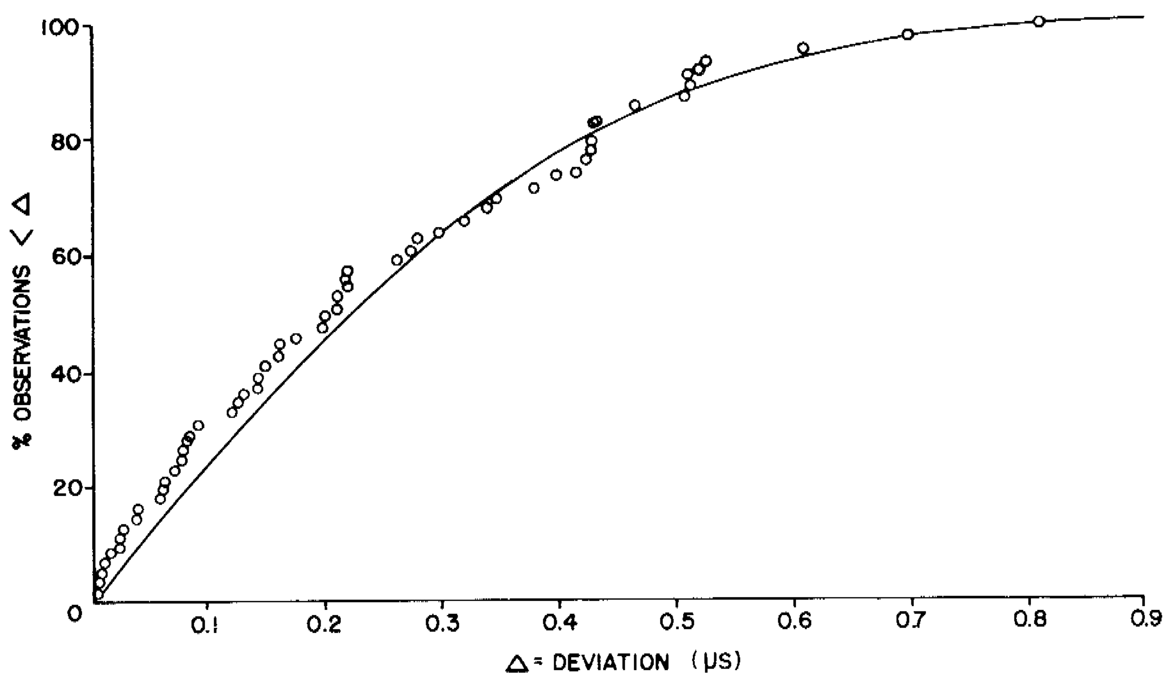

Fig. 5. SS7-Z Time Difference Deviation Magnitude Distribution.

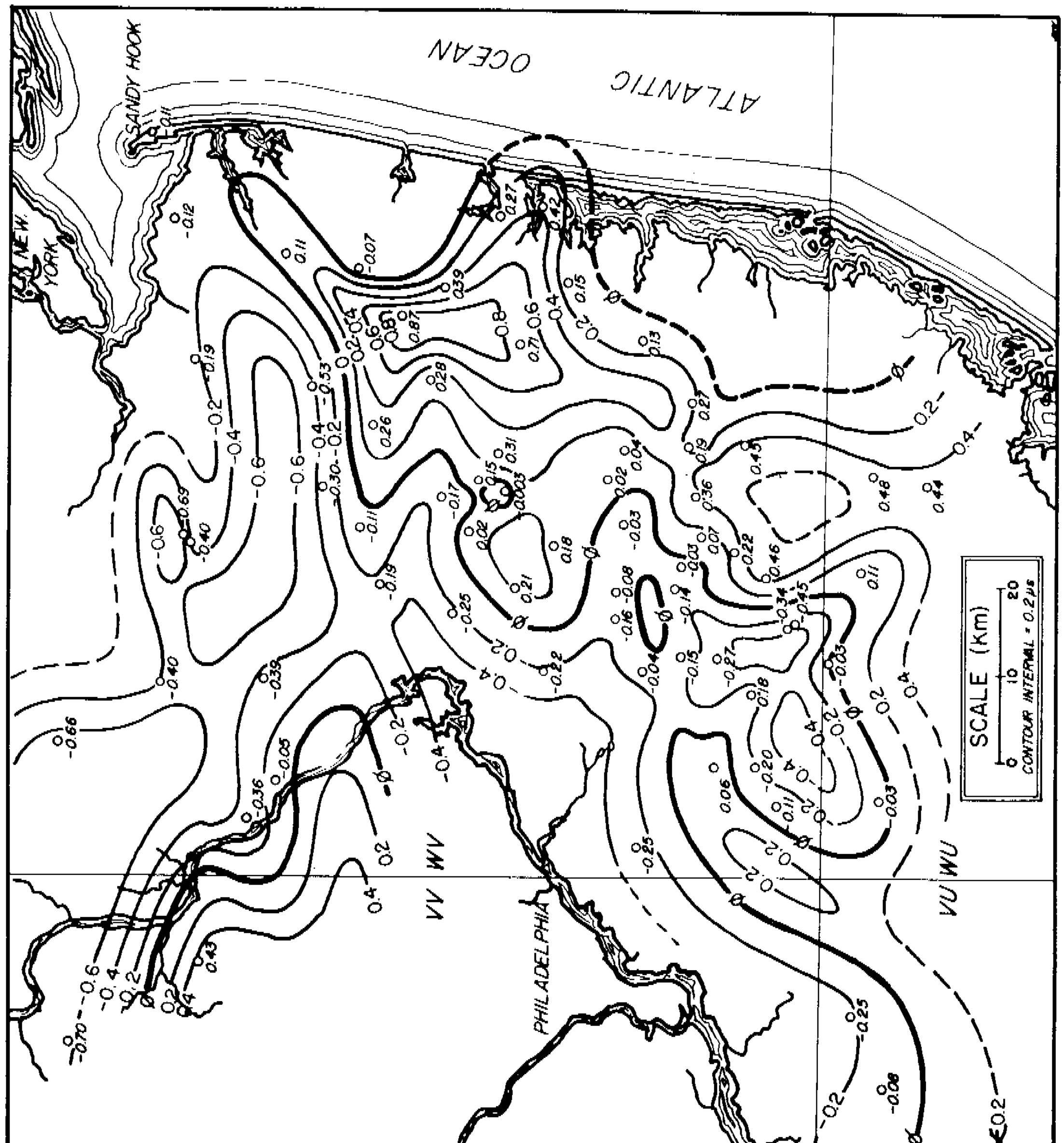

Fig. 6. Map Showing SS7-Y Time Difference Deviations from Theoretical Model.

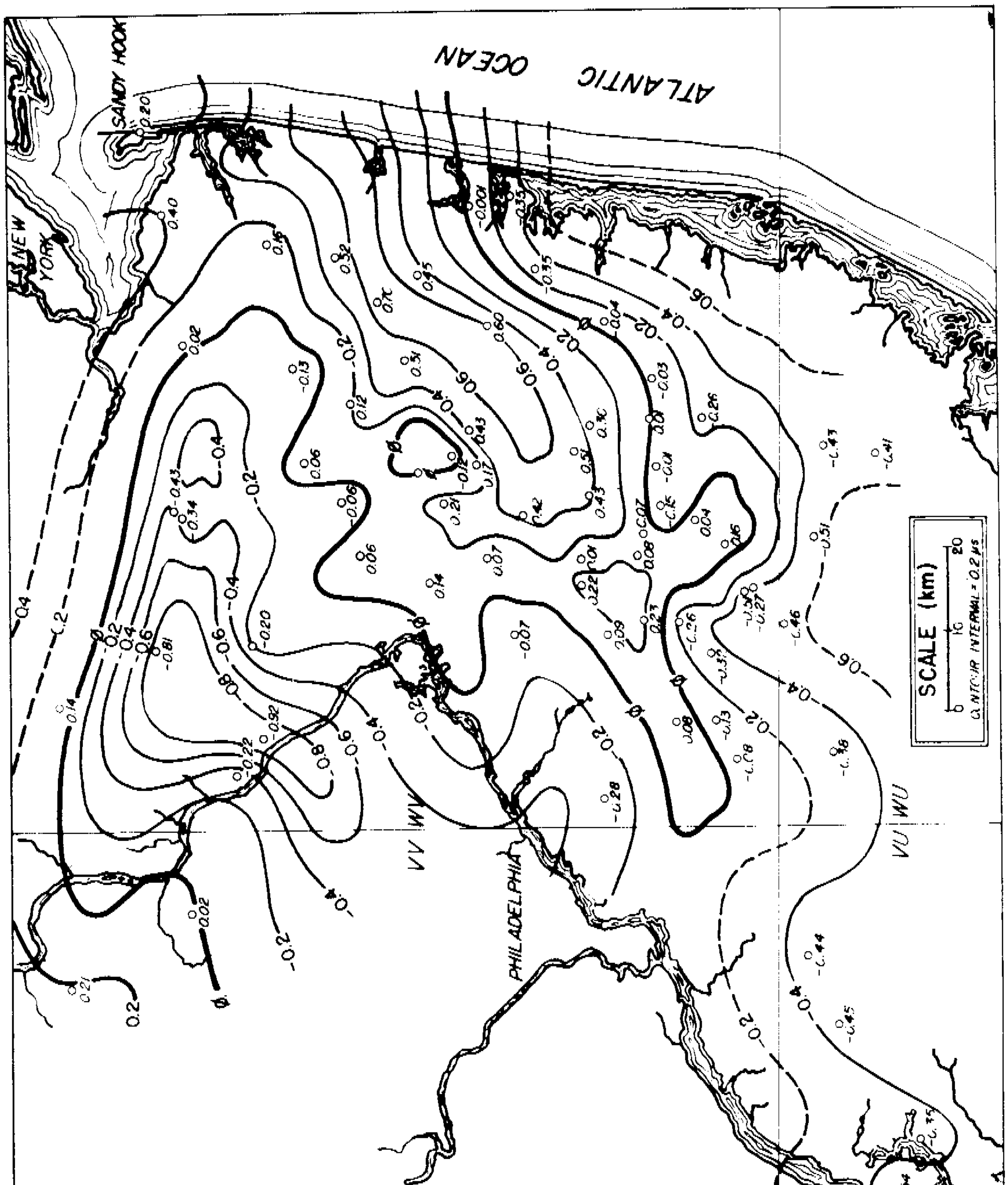

Fig. 7. Map Showing SS7-Z Time Difference Deviations from Theoretical Model.

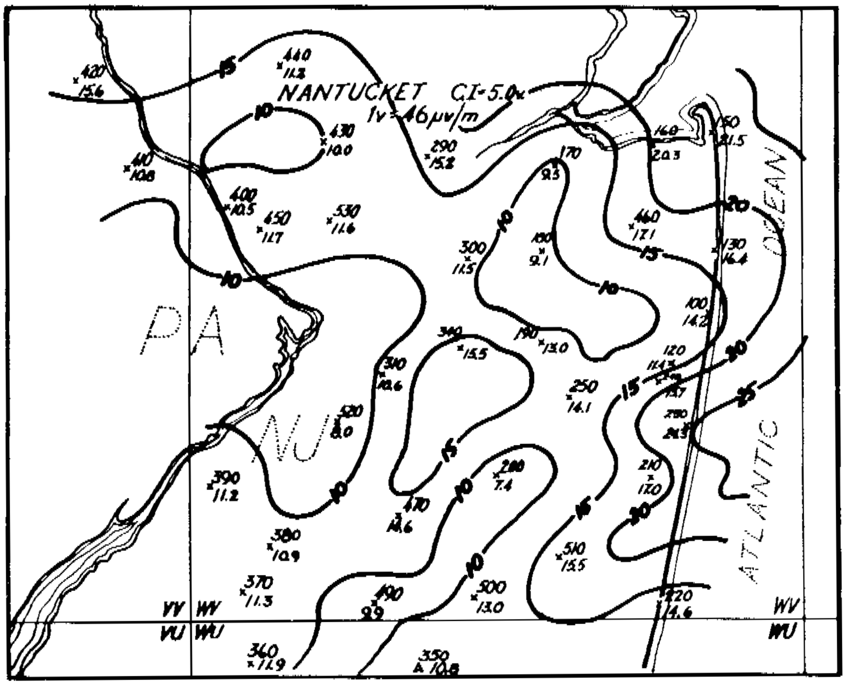

Fig. 8. Map Showing SS7-Y Field Strength Distribution.

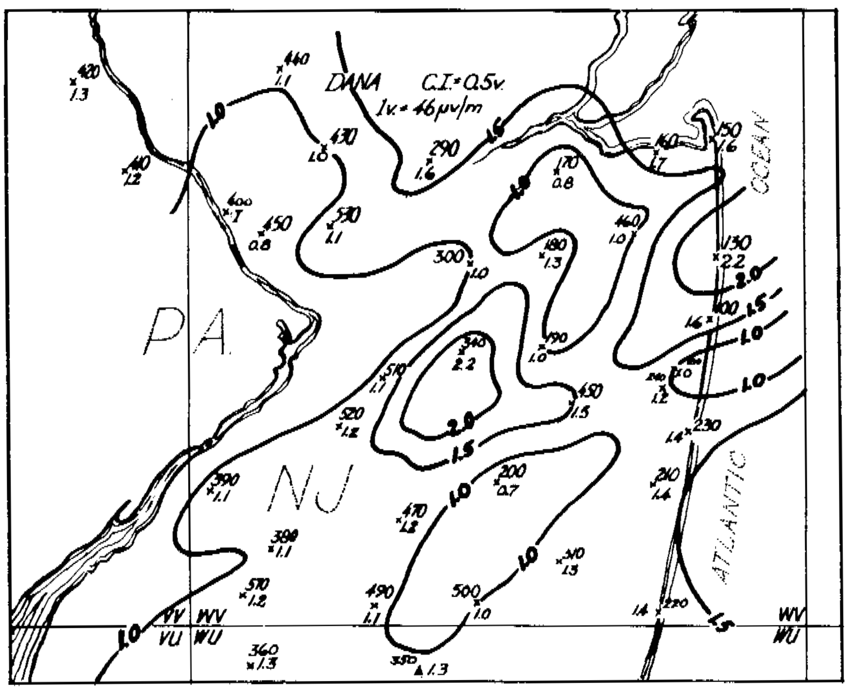

Fig. 9. Map Showing SS7-Z Field Strength Distribution.

values are the output voltage of the amplitude strobe of the timing receiver when tracking the third cycle crossover with an input attenuation of 40 dB. The indicated conversion constant of 46 μv/m/volt was estimated from the antenna characteristics to provide a corresponding approximate value of the field strength.

The phase of the Nantucket transmission relative to the reference point as a function of the distance from the transmitter is shown in Fig. 10. The plotted points are an average of measurements on six different days. The deviations of these measurements from a least squares fitted straight line are shown in Fig. 11. The experimental results have been corrected for loran chain variations from data furnished by the United States Coast Guard. The error bars in Fig. 11 represent typical uncertainty estimates arising from rubidium standard frequency offset.

DISCUSSION AND CONCLUSIONS

The simplified mathematical model presented provides a reasonably accurate description for a small segment of the coverage area, namely the 100 km square area. The observed magnitude of the deviations from the model are randomly distributed. Specific parameters of the model are sensitive to the size of the coverage area. In view of the simplicity of the model, strict interpretation of the parameters in terms of propagation properties is not possible. For example, the value of the parameter β for the SS7-Z slave shown in Table I (3.339 μs/km) is essentially the value expected for an all sea water path. [See Footnote (c).]

The time difference deviations and field strengths exhibit a pronounced areal variation. Furthermore, the contours of both variables exhibit a preferred orientation in a NE-SW direction. Figure 12 shows salient topographic and geological features of the test area. These features also exhibit a preferred orientation in a NE-SW direction. Consequently, there appears to be some correlation between contour orientation and the topographic and geological features.

The standard deviations of the time difference data are 0.33 and 0.22 μs for the 100 km square and the 60 km square, respectively. These values exceed the 0.18 μs estimated to arise from experimental sources. Clearly the results for the smaller test area are in better agreement with the theoretical model than are the results for the larger test area. The criterion for proximity of nearby overhead wires

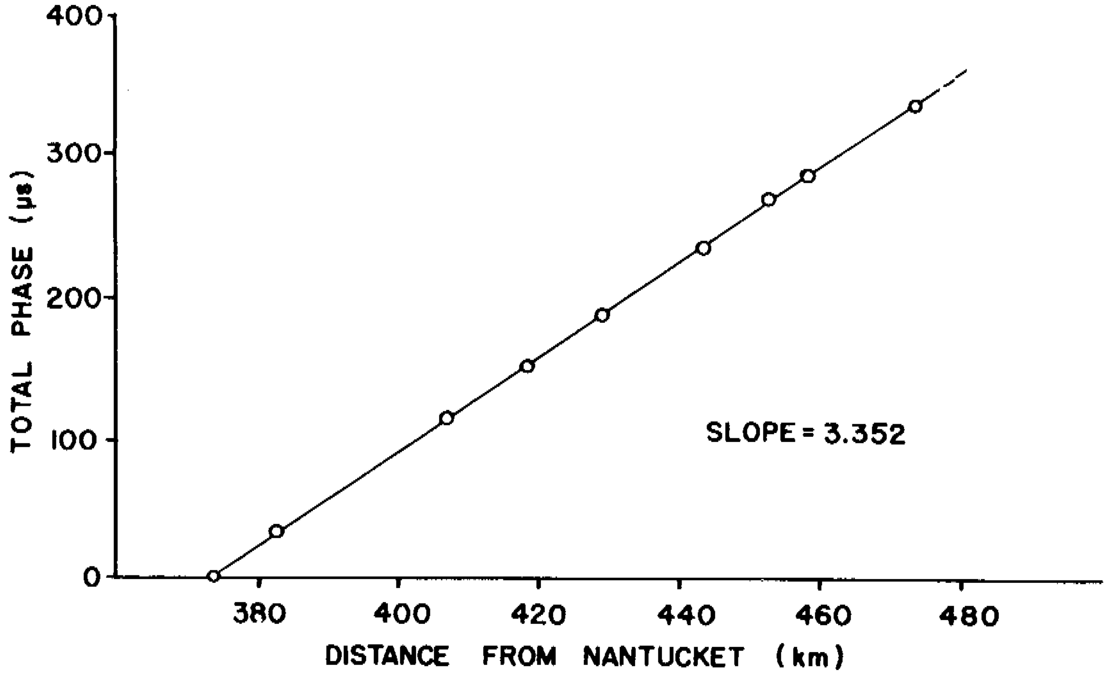

Fig. 10. SS7-Y Phase Variation vs. Distance.

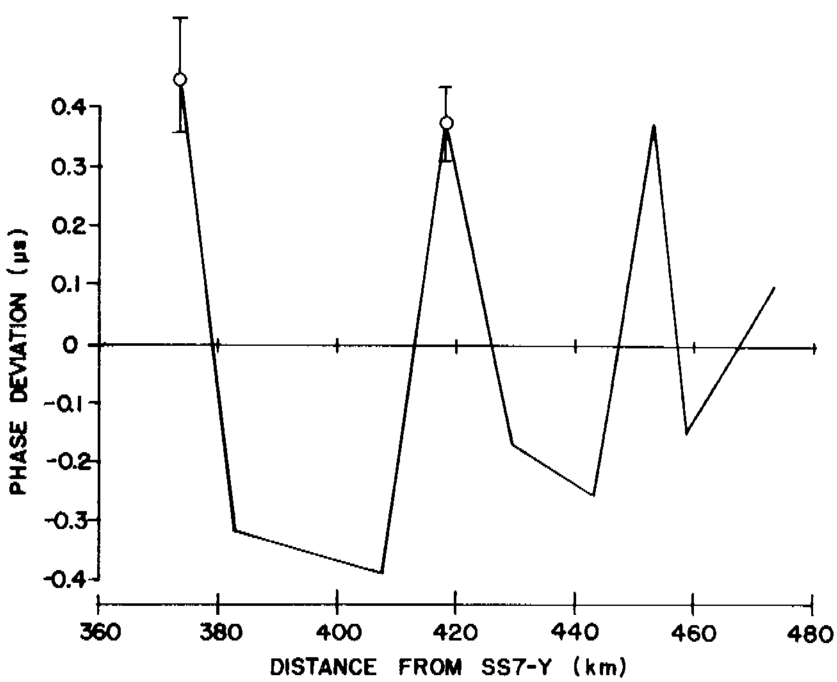

Fig. 11. SS7-Y Phase Deviation vs. Distance.

also influences the deviations from the theoretical model. Although the time difference data does not allow a definitive separation of the contributions of area size and proximity of overhead wires, both factors, as well as previously discussed topographic effects, appear to contribute to the deviations from the idealized model.

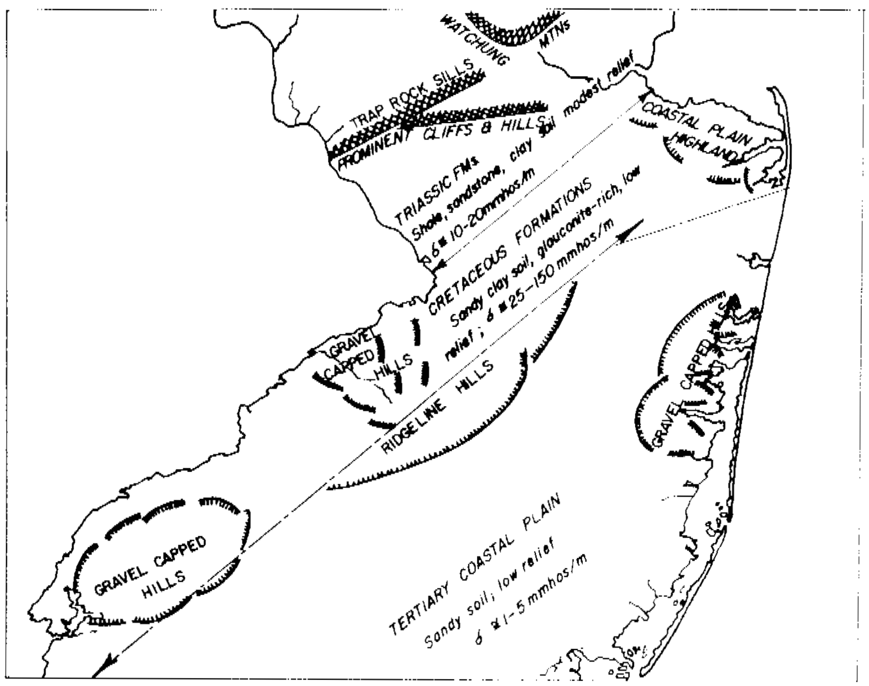

Fig. 12. Map of New Jersey Showing Salient Topographic and Geologic Features.

Preliminary measurements of absolute phase along a ray path from the Nantucket transmitter across the 100 km test area, yielded a linear variation of phase with distance from the transmitter. The least squares slope is 3.352 μs/km, with a standard deviation of 0.3 μs. These observations are considered to be consistent with the time difference measurements for the 100 km square. Since this particular ray path is located in a region of nearly constant conductivity and is devoid of terrain irregularities, it is assumed that the major contribution to the observed deviations arises from scattering associated with overhead wires.

These results are of importance to the position fixing accuracy of ground-deployed loran receivers. Randomly distributed time difference deviations of the order of 0.3 μs from an idealized model have been observed. This study suggests that scattering associated with topographic features as well as from man-made sources such as overhead wires contribute to the deviations. The results yield a realistic standard deviation of position location accuracy of the order of 60 meters.

ACKNOWLEDGMENTS

The authors are indebted to Lt(jg) A. A. Sarra, Jr., Coast Guard Loran Station, Carolina Beach, North Carolina, and to LCdr A. R. Trivers, Coast Guard Electronic Engineering Center, Wildwood, N. J., for assistance in obtaining information on the East Coast Loran Chain during October 1974.

The assistance of Mr. H. Garber and Mr. A. H. Zanella, USAECOM, in obtaining the field data is gratefully acknowledged.

A portion of the funding support for this research was provided by the Office of the Project Manager, Navigation and Control Systems (NAVCON), Fort Monmouth, New Jersey.

REFERENCES

[1] Johler, J. R., (1971), Loran radio navigation over irregular inhomogeneous ground with effective ground impedance maps, OT/ITS Research & Engrg. Report 22 (Supt. of Documents, U. S. Government Printing Office, Washington, D. C. 20402).

[2] Sodano, E. M. and T. A. Robinson, (1963), Direct and inverse solutions of geodesics, Army Map Service, Technical Report No. 7 (Rev.).

[3] Department of the Army (1967), Grids and Grid References, Department of the Army Technical Bulletin TM 5-241-1.

[4] Johler, J. R., and L. A. Berry, (1967), Loran-D phase corrections over inhomogeneous irregular terrain, ESSA Technical Report IER 59-ITSA 56 (Supt. of Documents, U. S. Government Printing Office, Washington, D. C. 20402).

Additional Background Information

(a) The assumption of identical propagation velocities over the paths D_s and D_m is implicit in Eq. (1).

(b) The interpretation of β as the reciprocal of a local propagation velocity is valid only to the extent that the propagation velocities over the paths D_s and D_m are identical.

(c) Furthermore, a change in the parameter α of 4 μs for two fits of the same area is devoid of physical significance. This behavior is related to the fact that D_s and D_m are large quantities so that in the least squares process, small variations in the parameter β are compensated for, by large variations in the parameter α. Additional physical constraints as discussed by Doherty [5] are necessary for a realistic physical interpretation of a statistical model.

---

[5] Doherty, R. H., (1972), A Loran-C grid calibration and prediction method, OT/TRER 25 (Supt. of Documents, U. S. Government Printing Office, Washington, D. C. 20402).

QUESTION AND ANSWER PERIOD

LCDR. POTTS:

What period of the day were these measurements made? Were they all about the same time during the day? Different days?

DR. PEARCE:

Not really. It's the question of utilizing a full day to make a full set of measurements. We get one stage and keep going, and keep going, and then as soon as we get back, by dark. There was a night day.

LCDR. POTTS:

Well, my question's related to the fact that in past studies we've observed strong temporal correlation, as Bob Doherty well knows, and I wonder whether this had an influence on your readings?

DR. PEARCE:

No, as I say, these are very preliminary. I haven't checked it, but it seems to me that it was done at a very short period of time. I can't remember any essentially serious changes in the general condition, like weather fronts for instance, or things like this that might enter into it.

LCDR. POTTS:

Have you removed any adjustments that the station made, during the period you were making these observations?

DR. PEARCE:

No, no. This is essentially the data averaged. We visited each maybe four times. A criteria like this may be on four different days, but not that far apart in time and in the course of the experiment I don't recall anybody making any comments about it. There was nothing obvious as far as adjustments and so forth were concerned.

LCDR. POTTS:

Well, the point is you wouldn't be notified of the small adjustments which are necessary to retain synchronization?

DR. PEARCE:

No, that's right.

VOICE:

These are on the order of multiples of 20 nanoseconds but it can be large as 100 nanoseconds at one time.

DR. PEARCE:

Right. This has all got to be checked out. As I said this is just preliminary. The thing that disturbed us is actually the magnitude of it.

MR. DOHERTY:

The magnitude of it is surprising. That is 9 points and you say that is more than one single reading at each point.

DR. PEARCE:

Oh, yes. We've been doing it and doing it again. So there is repeatability there, right. The error bars essentially are that you do a certain station right near the beginning or the end. We tried to do it so we do a little bit to take care of the offset in case it isn't quite what we think it is.

MR. DOHERTY:

You only have error bars on two of the nine.

DR. PEARCE:

That's right. I've only worked out two.

MR. DOHERTY:

But you think they're typical.

DR. PEARCE:

That is correct. These numbers are consistent with the specifications that we have for this particular unit, too, as far as fractions of microseconds per hours. It meets the specifications and it's been tuned up against the cesium.

MR. DOHERTY:

This would be a very nice path to do a prediction on.

DR. MUELLER:

One question, I guess, is related to the fact that according to Mr. Putkovich's chart definition or classification, there are microsecond people and millisecond people and so forth. I consider myself a meter person.

Therefore I have some difficulty converting microseconds and especially microvolts per meters into some metric quantity. So my question is a simple one. Let's assume that you take your model for computing the ground wave effect and we take the given equipment and we set it up on one of the Coast and Geodetic benchmarks. How close can you get in position in meters, or in feet if you wish?

DR. PEARCE:

Well, for this area 60 meters standard deviation.

DR. MUELLER:

Sixty meters standard deviation, a sixty meter difference?

DR. PEARCE:

No, that's from a data set, averaged over. Because some of those points were geodetic benchmarks.

DR. MUELLER:

And my second question is, taking not just the receiver but the whole system that you need for real time positioning, what is your estimate of the cost of such a system?

DR. PEARCE:

You're addressing a problem that is much more important than the technical features of this at the present time. At the present time it looks like it's running around $15,000 for the complete package: receiver, readout, time difference, geodetic coordinates, and we'll even throw a battery in for that. But one of the problems is it's too much. That is a nontechnical feature of this program.

QUESTION AND ANSWER PERIOD

MR. DOHERTY:

I wanted to make a little addition. Dr. Winkler started pressing me on this nanosecond system and how can you do it. So I wanted to mention a little bit more.

In the first place, we are doing an analysis on the differential loran experiment that was carried out on the East Coast summer of '73. The analysis there suggests that ten to 20 nanoseconds capability exists between two stations. When we started looking much more closely at, why isn't it there continuously, we discovered the primary reason was that the 10 to 20 nanoseconds capability is not there at all times. This is because there are variations that occur at the transmitting stations in excess of this.

In the summertime, we were not able to find any propagation effects that were anywhere near as large as the variations that occurred within the chain. This suggests that an improvement in the chain could give you the type of nanosecond type timing or naviation. I should say navigation. With timing, you get into another problem, that is you've got to know your system. There should be an R in there, which is the receiver constant which then gets into the people problem.

Now the people problem I very much appreciate. I wanted to mention that we are presently doing a calibration of the Fort Hood chain down in Texas. It's a new Loran-C type chain and it's been recently installed down at Fort Hood, Texas and installed with a new concept. And that is that the transmitting stations are completely unmanned.

They are put in. They are turned on and they are left on—they're unmanned. As far as we've been able to determine to date, we seem to be getting our nanosecond type resolutions from this chain. Now, it's too early to say that this is definitely the case and it's too early to say you can get by with an unmanned chain continuously and it's far too early to say you can use Loran-C type powers with that concept. I want to give due credit to the Coast Guard in that I know that they paid for the work that developed the chain down at Fort Hood. It was sold to Megaparts but the Coast Guard hired—paid Megaparts to develop the transmitters that are actually being used at Fort Hood. But it looks as though this may be a very valid concept and I think it's one well worth considering.

The Fort Hood chain can be controlled by telephone data link. So from the monitoring station you can put in corrections but our experience has been that if maybe you can put in a slight shift once a day that it tracks within the order of a nanosecond through a day. Now we can't say over the time period that these people were talking about on their slides here today, because we've only got a few weeks worth of operation.

DR. MUELLER:

I'd just like to make one comment, I guess, on the question which came up several times this afternoon in different contexts. One was the comment of Dr. Winkler on Mr. Chi's slide which showed the differences between UTC (USNO) and the BIH and later the differences between the Loran-C transmissions and the UTC (USNO). And I guess the question also has some implications on the timing requirements that could be imposed on the Loran-C network.

The problem from the user's point of view, and I'm a user for those of you who don't know, is merely a question of being able to use the time signal as it comes or whether you have to apply some corrections to it. An analogy can be shown here of what happens, for example, in the use of UTC transmissions just lately. In the past, the difference between transmitted UTC and UT1, (UT1 is the time the user is interested in) was kept within, something like 50 milliseconds or so and if the Earth's rotation changed in such a way that the deviation from UTC was more than say, 50 milliseconds, a one-tenth of a second step adjustment was recommended by the BIH, together with some phase adjustment which changed the slope.

At that time, most geologists were satisfied with the time signal as it came. We didn't have to apply corrections to it. At some time a decision was made that the slope, the phase adjustment, should be eliminated and the step adjustment should be made in one second steps. Now the maximum deviation between UT1 and UTC may be as much as 0.8 of a second and this is, of course, unacceptable.

The geologist has to go to various tables published by the Naval Observatory and/or by the BIH to apply corrections to get UT1, which is fine. Of course, we think geologists are well educated and can make simple corrections like that, especially if somebody makes these corrections available. But the point is once you have made corrections, it doesn't make any difference how many of these numbers you have to add together. So as far as we are concerned, there is no advantage really for us in that Dr. Winkler made only a single adjustment in his UTC over that three year period, because if you would have made ten adjustments, that simply whould have meant that we have another number to add to our corrections to get back to some kind of reference.

But that's not the point. The point really is that the important requirement here is the realization and the continuation of very high accuracy monitoring systems.

So that the difference between the different systems could be made available to the users who then can correct their observations to the proper reference.

So, for example, if the Loran-C, if in the Loran-C network, the oscillators would not be phase adjusted and step adjusted as frequently as they are now or if in the future networks make no requirement whatsoever would be imposed on these stations to be set up, but the Naval Observatory still could let us know how big these differences are.

All right. We could live with that, that's really the only real requirement, besides monitoring and the continuous frequent distribution of the corrections. The rest is convenient—not a requirement.

DR. REDER:

I have a question on the advisability of making clock adjustments of people who are participating in the BIH time scale. Why did you do it? Are you pulling your own shoestrings? No?

DR. WINKLER:

This is an extremely crucial point.

The input into the BIH comes from individual clocks. No adjustments. Theoretically, yes. The Naval Observatory master clock is one which is steered to coincide with a coordinated time scale and there is an essential difference between these. Now I repeat what I said. The individual clocks which provide input to the BIH, and there are at the moment I believe some 60 individual clocks, are supposed to be, I underline that five times, without adjustments.

It is known, I know, that it is not true in all cases, but you must consider this really as a problem which is beyond discussion here.

DR. REDER:

Your individual clocks which are used in the BIH case, are not adjusted.

DR. WINKLER:

They're not adjusted. The measurements given to the BIH every ten days are clock readings against a Loran reading and of course by the chain of Loran and so eventually the BIH uses these individual clocks.

DR. REDER:

Now how do you adjust your master clock? Is that only on paper?

DR. WINKLER:

No. We, of course, want to provide a time scale which is better than any individual clock. In order to do that, we must adjust an arbitrary clock. In fact, it's not an adjustment of that clock; it's a phase adjustment of a clock's output, and we have in fact three clocks driven from one and the same frequency standard, and there are several such systems available.

So that is a clock where the individual variations of the driving frequency standard are taken out. You must look at that adjustment as a compensation for the long-term variations of the driving frequency standard.

DR. REDER:

So your master clock is not the average of those individual clocks which participate in the BIH?

DR. WINKLER:

Not necessarily. In fact, the two systems have only loose connections, but it is our attempt to provide a time reference tick, a one pulse per second, which is both as uniform as possible and in the long run does not deviate very much from BIH because there are additional consideration to what Prof. Mueller just said.

In fact we have a written requirement from the U.S. Coast Guard to minimize these changes in frequencies. The requirement was sent to us from your office two or three years ago. To minimize the number of even these intentional long-term changes to plus or minus one part in 10^{13}. That's the level of the coordination offset. Anyone who is concerned about that kind of precision of plus or minus one or two parts in 10^{13}, ought to receive our Series 7 regular bulletins which are concerned with the time scales and astronomical observations.

DR. GUINOT:

Of course the clocks which participate in the BIH computation should be independent.

If some are adjusted, people are requested to give the amount of the adjustments so that it may be taken into account by the BIH. Generally this does not happen, and the clocks are completely independent.

DR. KLEPCZYNSKI:

On Series 7 we distinguish several different types of time, USNO (MEAN) and UTC (USNO) and they are not necessarily the same thing.

DR. WINKLER:

Now that of course requires a third generation of people. That's the nanosecond people.