Forum

An Evaluation of the Increase in the Quality and Quantity of Navigational Information Available from Low-Frequency Radio Navigation Systems

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1. INTRODUCTION. Low frequency radio navigation systems continue to play an important role in the provision of precise navigation for vessels sailing in coastal waters, and in other zones requiring high accuracy. Modernization of the existing Loran C chains, and deployment of new ones, shows there is strong interest in these systems despite the appearance of global navigation satellite systems (GNSS) such as 'Navstar' and 'Glonass'.[1] This continuation of interest is connected to the relatively low cost of operation of the systems, the low cost of receiver-indicators and the need to provide users with very precise but reliable positioning information, which at present can only be obtained by joint use of GNSS and Loran C.[2] To make the most of such an approach, Loran C should provide accuracy and reliability similar to GNSS.

2. USE OF ADDITIONAL INFORMATION. In the conventional use of a Loran C chain, when only two navigation parameters are measured, integrity is reduced by the inherent shortage of information; there is insufficient redundancy for high reliability and the zone of high accuracy of position is limited in area. One of the ways of solving these problems is to use non-traditional methods, such as measuring additional navigation parameters between pairs of Slave Stations (SS), thus increasing the redundancy of information. The essence of these methods is described in References 3, 4 and 5. This paper considers the possible increase in quality and quantity of navigational information made available by using additional parameters.

Measurements of additional parameters can be used to form extra navigational isolines. Figure 1 (see p. 412) shows an example of the location of basic navigational isolines obtained by measurements of parameters in a traditional way (depicted as solid hyperbolic lines), and the additional navigational isolines obtained by non-traditional methods (shown as dashed hyperbolic lines). The total number of isolines is increased and can be determined by the formula for the number of combinations from n elements by m:

$$C_n^m = \frac{n!}{m!(n-m)!}, \tag{1}$$

where:

$c =$ number of combinations from n by m,
$n =$ total number of stations in a chain, including the Master Station (MS),
$m = 2$ – for the considered case.

Proof of the probable increase in accuracy of position using basic and additional lines of position, was given in Reference 4.

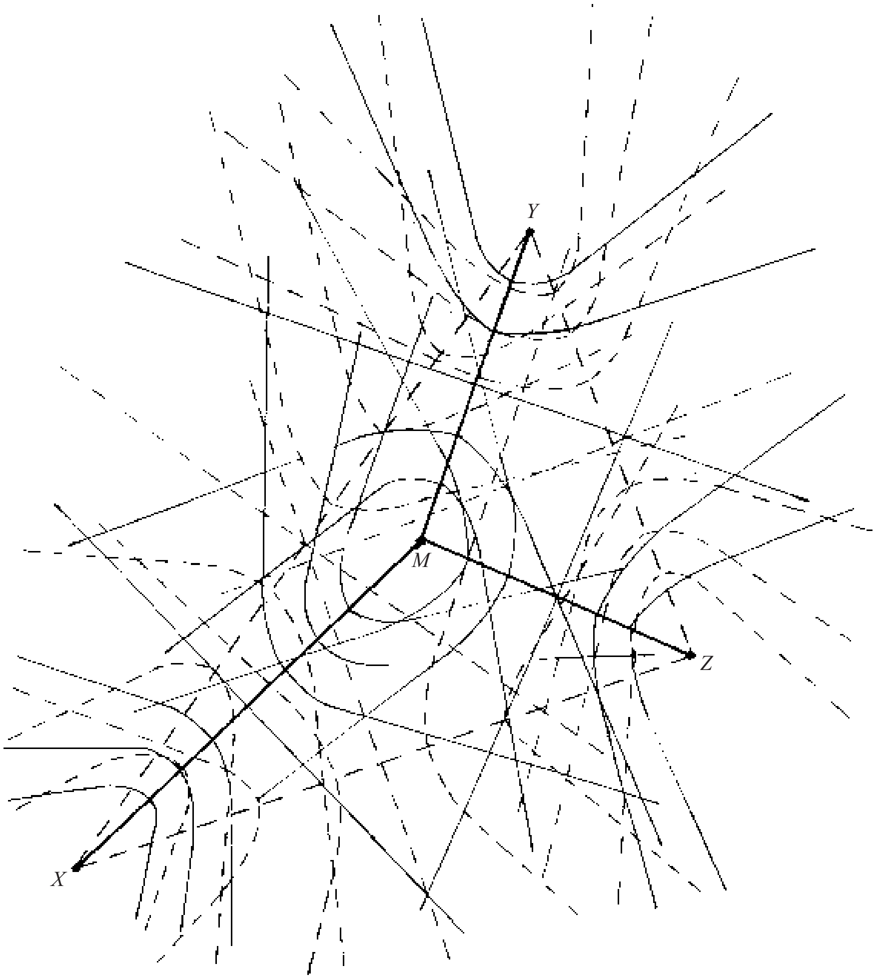

Figure 1. Location of navigational isolines.

3. ADVANTAGES OF USING ADDITIONAL LINES OF POSITION (LPs).

3.1. *Reduction in the Error of Definition of a LP.* The error of definition of a LP (σ_l) is determined by the formula:

$$\sigma_l = \frac{c \cdot \sigma_\tau}{2 \cdot \sin(\psi/2)}, \tag{2}$$

$c =$ speed of propagation in metres per second;

$\sigma_\tau =$ mean quadratic error (MQE) of measurement of time delay of signals in seconds;

$\psi =$ the baseline angle in radians.

Considering the baseline angles from a vessel at position C (Figure 2), it can be seen that, in most cases, the baseline angles on additional pairs of stations are sums of the baseline angles on pairs between MS and the appropriate SS. By expressing baseline angles of additional pairs through basic pairs, for the considered case, we arrive at:

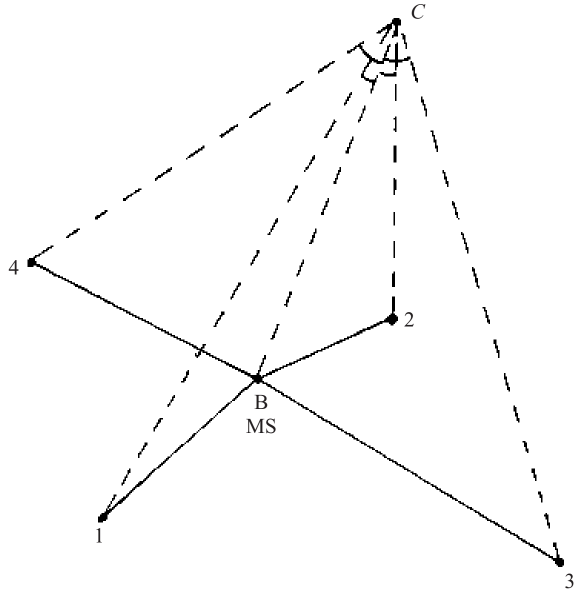

Figure 2. Baseline angles from a vessel at position C.

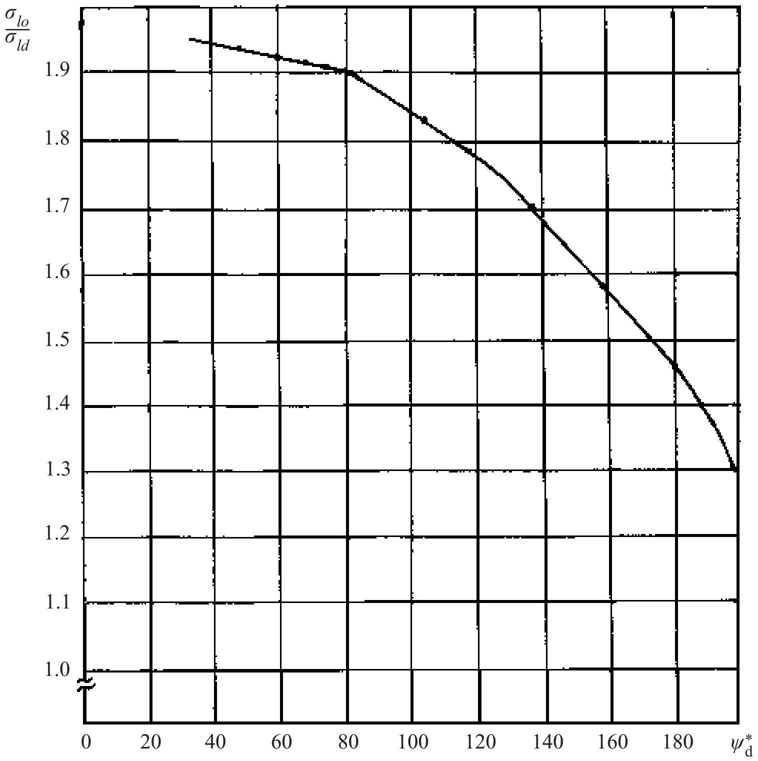

Figure 3. Relation σ_{lo}/σ_{ld} against the distance to the MS.

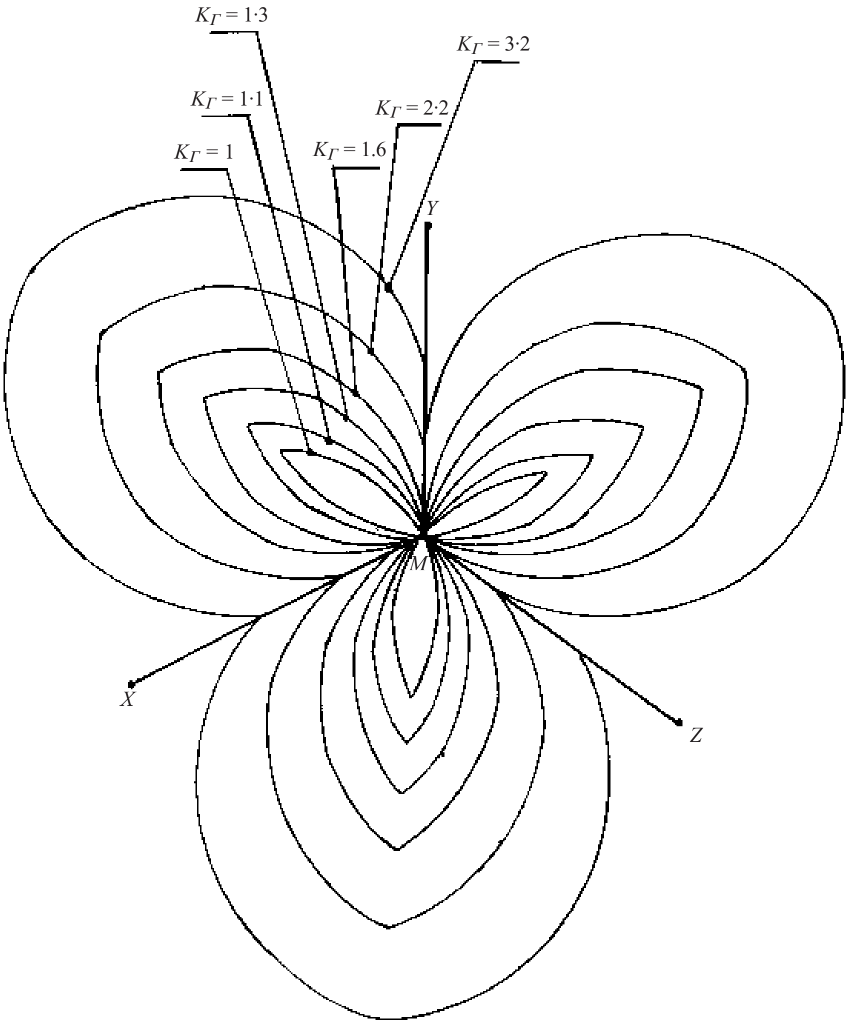

Figure 4. Zones of accuracy for traditional use of a chain from MS and three SS.

$$\begin{cases} \psi_{1,2} = \Psi_{B1} + \Psi_{B2} \\ \psi_{1,3} = \Psi_{B1} + \Psi_{B3} \\ \psi_{1,4} = \Psi_{B4} - \Psi_{B1} \\ \psi_{2,3} = \Psi_{B3} - \Psi_{B2} \\ \psi_{2,4} = \Psi_{B2} + \Psi_{B4} \\ \psi_{3,4} = \Psi_{B3} + \Psi_{B4} \end{cases}$$

Analysis of the various arrangements of a user and transmitting stations brings a conclusion that the baseline angle of a pair of SS is the sum of their angles with the MS, when the line to the MS falls inside the angle formed by the pair of SS. The converse is also true, i.e. the baseline angle is the difference between their angles with the MS, when the line to the MS falls outside the angle formed by the pair of SS.

To evaluate the decrease of the error of definition of additional LPs in relation to basic LPs, the change in magnitudes of baseline angles of basic and additional station pairs was simulated with various distances of a vessel from the baseline. If it is accepted that the errors of

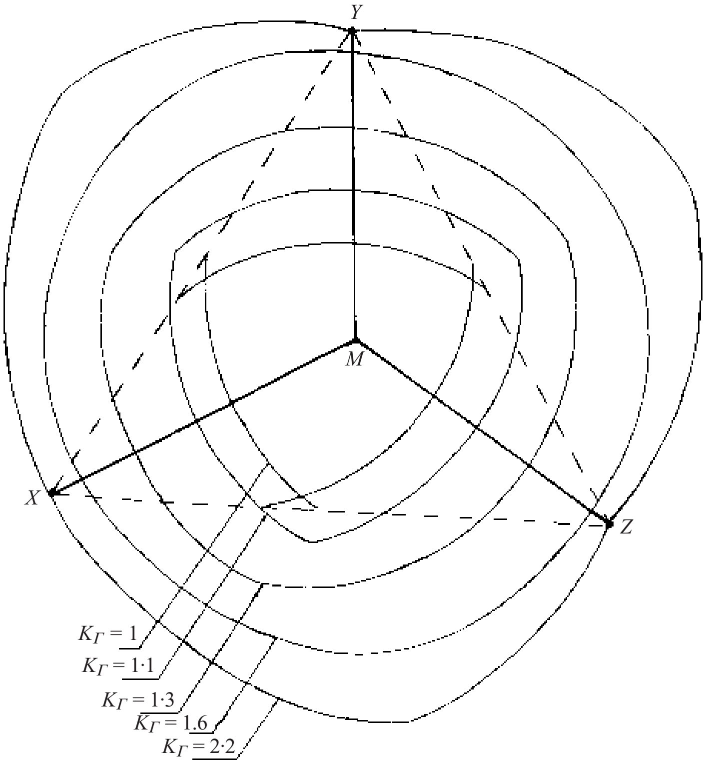

Figure 5. Zones of accuracy for pairs of SS.

measurement of basic and additional parameters are identical, then the relationship of MQE of the basic LP σ_{lo} to additional σ_{ld} will be:

$$\frac{\sigma_{lo}}{\sigma_{ld}} = \frac{\sin(\Psi_d/2)}{\sin(\Psi_o/2)}, \tag{3}$$

where:

Ψ_o = baseline angle on a pair of stations MS–SS;
Ψ_d = baseline angle on a pair of stations SS–SS.

The relation σ_{lo}/σ_{ld} against the distance to the MS is shown on Figure 3 (see p. 413).

Analysis of the graph shows that, with increasing distance from stations, the error of definition of additional LPs is decreasing. This conclusion is in agreement with the theoretical principle that, with range-difference parameters over large distances, the increased length of the baseline reduces errors of a system proportionally to quadrate of the length (see Reference 6).

3.2. *Reduction in the Geometric Factor* (*GF*). At uniformly precise measurements for a pair of LPs, GF is equal to:

$$\Gamma = \frac{1}{2 \cdot \sin\alpha} \cdot \sqrt{\frac{1}{\sin^2(\psi_1/2)} + \frac{1}{\sin^2(\psi_2/2)}} \tag{4}$$

where:

α = the angle of interception of LPs,
$\psi_{1,2}$ = the baseline angles, respectively, on the first and second pairs of stations.

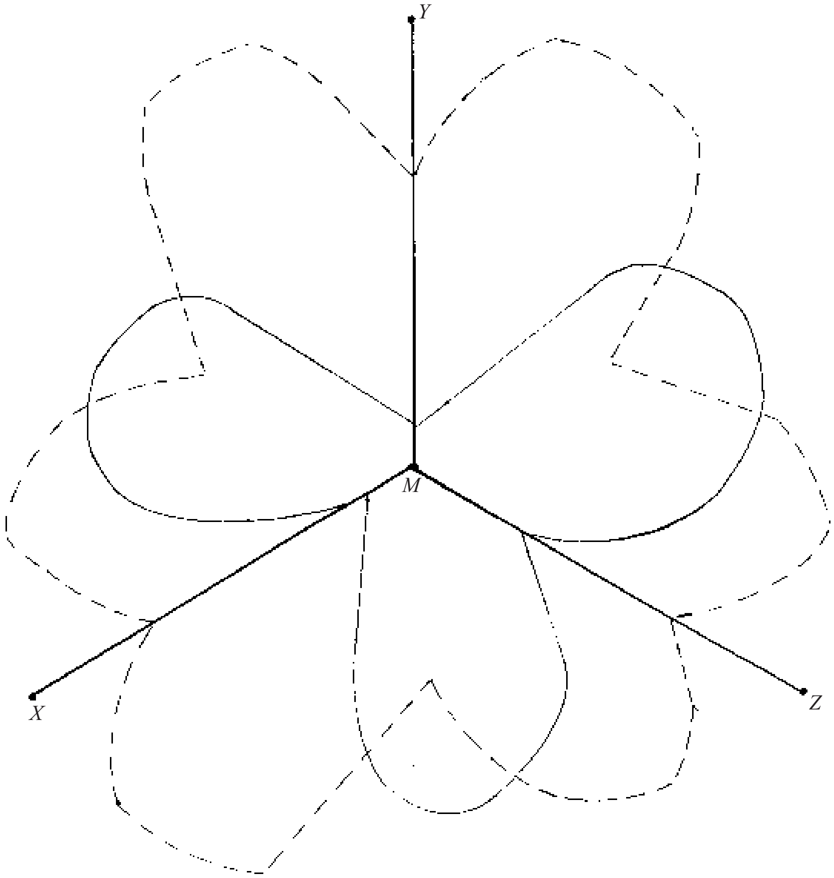

Figure 6. Results for zones of equal accuracy. ——, $K_\Gamma = 1$ on two LPs; – – –, $K_\Gamma = 1$ on six LPs.

From (4) above, as the baseline angles for additional LPs are increased, GF decreases.

In Figure 4 (see p. 414), zones of equal accuracy are shown for the traditional use of a chain from MS and three SS. They are constructed from a ratio:

$$\sigma_r = K_\Gamma \cdot c \cdot \sigma_\tau,$$

where:

σ_r = mean quadratic value of a radial error of vessel's position on two LPs;

$$\sigma_r = \frac{\sqrt{\sigma_{l1}^2 + \sigma_{l2}^2 - 2 \cdot \sigma_{l1} \cdot \sigma_{l2} \cdot \rho \cdot \cos\alpha}}{\sin\alpha};$$

$$K_\Gamma = \frac{\sqrt{\sin^2(\psi_1/2) + \sin^2(\psi_2/2)}}{2 \cdot \sin(\psi_1/2) \cdot \sin(\psi_2/2) \cdot \sin((\psi_1 + \psi_2)/2)}.$$

K_Γ is a tabulated factor, and special tables are composed for its determination. It is also possible to build zones of equal accuracy in a graphic manner (see Reference 7).

From Figure 4, it can be seen that the best accuracy is provided only in a limited zone close to the MS. By building similar zones of equal accuracy for pairs of SS (Figure 5, p. 415), the following conclusions can be drawn:

(a) Zones of equal accuracy on Figure 5 look like intersected *petals*.

(b) The area of a zone of equal accuracy on Figure 5 is greater than the similar area on Figure 4.

This can be explained as follows: while using pairs of additional LPs, increases of baseline angles ψ occurs. Such increases result in a reduction in the magnitude of K_{Γ}. As the function $y = \sin(\psi/2)$ grows with increase of argument ψ faster than the function $y = \sin^2(\psi/2)$, to obtain the same value K_{Γ}, it is necessary that the angles ψ are equal. This can only be achieved by moving the vessel's position further away, which results in larger areas for the appropriate zones of equal accuracy while using additional LPs.

3.3. *Improved Accuracy of Position*. The accuracy of determination of the vessel's position close to SS becomes comparable with accuracy close to MS. Using additional LPs also improves the reliability of obtaining navigational information, as a failure of one station has a lesser effect on the availability of data than when using traditional methods.

To evaluate the increased accuracy of a vessel's position and build the zones of equal accuracy while using basic and additional LP methods, simulation was applied.[8] The simulation was completed for a chain with a MS and three SS, located in a typical star scheme. The points of true vessel's position were uniformly distributed on azimuth and distance from MS. At each point, a simulation of 100 observations on two LPs and 100 observations on six LPs was made.

From the simulation, results for zones of equal accuracy (Figure 6) were drawn with a solid line for $K_{\Gamma} = 1$ on two LPs and with a dashed line for $K_{\Gamma} = 1$ on six LPs. Thus, the simulation confirms the hypothesis that, the use of navigational information made available by measuring additional parameters, improves the accuracy of position determination, provides a better distribution of zones of equal accuracy, and enlarges the area of zones of equal accuracy.

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KEY WORDS

1. Navaids. 2. Loran C.