Loran-C in a European Navigation Perspective

Börje Forssell

(*Norwegian University of Science and Technology*)

After a brief overview of Loran-C system operation and performance, the present situation of the system in Europe is described. Loran-C is now in operation under the NELS agreement in north-western Europe in newly established chain configurations with old and new transmitter positions. Parallel to Loran-C the Russian equivalent, Chayka, is also operating, with three chains in Europe. There is an agreement between Norway and Russia concerning cooperation and possibly joint chain operations between the two system providers in the north; similar agreements in the Baltic and Mediterranean/Black Sea areas are being worked on. The situation around the Iberian peninsula has not yet been clarified. Being the only long/medium-range terrestrial system in Europe in the 2000+ time frame, Loran-C could be seen as a supplement to satellite systems. Due to the good penetration properties of its low-frequency signals, it can be used in many circumstances where satellite systems fail because of limited satellite visibility. Integration of Loran-C and (differential) satellite receivers, where Loran-C is calibrated by the satellite system as long as there are enough visible satellites, could in fact give the best of both worlds. For this reason, Loran-C is being considered in the perspective of a future international, civil satellite navigation system, initiated in Europe.

1. BRIEF OVERVIEW OF SYSTEM OPERATION. Loran-C is a terrestrial radionavigation system which is a descendant of similar systems developed in the USA during the Second World War. Most Loran-C receivers are used for maritime navigation, but important user groups are also land navigation, timing and aviation, particularly general aviation in the US. The total user population is about 1·3 million. Loran-C today covers the north American continent and adjacent waters (except for the northern parts of Canada), east Asia waters and coastal areas from the South China Sea to the Bering Strait, and north-western Europe from the Bay of Biscay to the Barents Sea.

Traditionally, Loran-C has been used as a hyperbolic system, i.e. user positions are determined by means of measured differences in times-of-arrival (TOA) between signals from synchronised transmitters at surveyed positions. In recent years, increasing use of the system as a ρ–ρ system has been observed. This method, which implies position determination by means of measured distances to transmitters, requires high-accuracy user clocks or accurate time determination by other means.

Loran-C signals consist of pulse-group modulated carriers at 100 kHz. The band 90–100 kHz contains 99 percent of the transmitted pulse power. Each group contains eight pulses (nine from the master transmitter) spaced at 1 ms intervals. (The ninth master pulse is two ms behind the preceding pulse for identification and other purposes.) Each pulse has a length of about 250 μs with

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a mathematically well-defined rising edge. The grouping of pulses is used to increase the signal-to-noise ratio (S/N) in the coherently integrating receivers.

Transmitters are arranged in chains with 2–5 transmitters in each. Chains are identified by their characteristic group repetition intervals (GRI), i.e. the time between two consecutive starts of the first master pulse. 10 ms < GRI < 100 ms.

Receivers determine the TOAs by measuring phase differences at (usually) the third positive-going zero-crossing of the carrier at the rising edge of the pulse. This point is used in order to minimise the risk of interference from skywaves, i.e. ionospherically reflected signals, which are usually delayed more than 30 μs.

Transmitters consist of high-power, very precisely time-controlled solid-state generators, feeding large antenna constructions. The transmitted pulse power is in the order of 200–1000 kW, and antenna heights about 200 m. Usable ranges are in the order of 1000–2000 km. A more detailed system description can be found in Reference 1.

2. SIGNAL PROPAGATION. Signals at 100 kHz are propagated not only along the line of sight but also along the (curved) Earth's surface. The attenuation of the ground wave is mainly determined by the surface conductivity along the signal path, and this is the reason for the long range over sea water and the reduced range over land. But depending on field strength, signals can also be received behind man-made and natural obstructions, e.g. in cities, deep valleys and tunnels. This long range and the penetration ability is one of the reasons for the usability of the system in confined waters and in land navigation. However, as propagation velocity is a function of Earth conductivity, conductivity variation causes measurement errors. In fact, such variation is usually the largest source of error in Loran-C.

It is possible to compute signal propagation velocity with high accuracy over land, if conductivity parameters along the propagation path and to a certain depth are known. However, it is a very demanding operation. A more practical solution is to use a simplified propagation model in the area of interest, combined with sample measurements at selected reference positions; the model parameters are adjusted to match measurement values at the reference points. The model is then used for interpolation between reference positions. Depending on accuracy requirements, these models should include seasonal and diurnal variations, caused by ground conductivity fluctuations and weather influence (part of the signal power is propagated in the atmosphere). However, combining propagation modelling and sample measurements is also a relatively demanding task, above all in coastal waters and on land with varying topography. The method is being developed for automatic propagation mapping of areas of interest by means of recording receivers onboard vessels in regular traffic, using DGPS as position and timing reference.[2] Recorded and processed parameters can be stored as calibration values in commercial receivers.

Integration of Loran-C and DGPS receivers is an interesting method to utilise the advantages of both systems. Loran-C is then (almost) continuously calibrated by DGPS but supports accurate navigation in periods of reduced satellite availability (see below).

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3. ACCURACIES. As indicated above, position accuracy is to a large extent determined by propagation parameter uncertainty. If there are no land areas along the signal path, these parameters are accurately known and fluctuate only by weather influence. Position accuracy is then generally in the 50–90 m range (95 percent) in the central area of a chain. Because of signal attenuation causing reduced S/N values towards the periphery of the coverage area, the accuracy deteriorates with increasing distances from the transmitters. The coverage area of a Loran-C chain is often defined as the area within which the position accuracy is better than a quarter of a nautical mile. It should be added that repeatable accuracy is much better than absolute accuracy due to the fact that propagation parameters vary quite slowly. Normal values for repeatable accuracy are 20–50 m.

Atmospheric noise is usually much larger than receiver thermal noise in this frequency band, but the largest noise source, particularly in Europe, can be interference from other radio transmitters in adjacent frequency bands. For this reason, receivers contain a number of notch filters, automatically adjusted and/or programmable.

4. LORAN-C IN EUROPE. Most Loran-C chains were established and initially run by the US Coast Guard (USCG). In 1994, however, the USCG withdrew their support of the system outside the USA, leaving host countries to decide whether to continue system operations or not. In north-western Europe, Denmark, France, Germany, Ireland, The Netherlands and Norway, decided to join their efforts in modernising existing transmitters and establishing some new ones, thus enlarging coverage to all coastal waters and adjacent areas from the Bay of Biscay to the Barents Sea. A particular organisation, NELS (North-west European Loran-C System) was formed to establish the new chain structure and to run the system in this area. The system is now up and running, with the exception of a planned station in south-western Ireland which has been delayed.

The NELS transmitters will be time-of-emission (TOE) controlled, when the system is declared operational (without the Irish station) in April 1998. TOE control means that all transmissions are tied to a common time reference, in this case UTC as defined by the system time control in Brest, France. Time accuracy shall be better than 100 ns (95 percent) between all stations, and better than 30 ns between stations in one chain. This is particularly useful for cross-chain navigation, i.e. receivers using signals from more than one chain at a time.

There was also a USCG operated Loran-C chain in the Mediterranean area. For various reasons, this is no longer fully operational, but there are talks between different countries to try to re-establish and possibly increase coverage by similar measures and agreements as those used by NELS. These efforts are very much supported by the Commission of the European Union (CEU) with the pronounced purpose of using Loran-C as a terrestrial radionavigation system in Europe at least until the year 2010. The goal is to cover not only the Mediterranean but also the waters west and southwest of the Iberian peninsula and adjacent areas. In order to speed up development in the Mediterranean area, one solution may be to enlarge NELS coverage to include the two Italian stations

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in the Mediterranean chain. These are still running, and Italy, which is the most active among the Mediterranean host nations, has shown interest in such a solution.

Chayka is a system similar to Loran-C but established by the (former) Soviet Union and now covering central and western parts of European Russia, the Russian Pacific coastal waters and large parts of the Arctic Ocean waters and some adjacent land areas. Chayka operations will continue beyond 2010 according to the CIS Radionavigation Plan. Modern Loran-C receivers can also utilise Chayka transmissions.

There is an agreement between Norway and Russia to try to establish a joint Loran-Chayka chain in the Barents Sea by connecting the northernmost NELS chain (the Bø chain) to the western Arctic Ocean Chayka chain through the Tumanniy station on the Kola peninsula, in a similar way to the existing joint US–Russian chain in the Northern Pacific area. Talks are going on between Russia and Germany to increase coverage in the Baltic area by connecting the western station (Slonim in Belorussia) in the Chayka European chain to the NELS station in northern Germany (on the island of Sylt). Similarly, there is pronounced Russian interest in the re-establishment of Loran-C coverage in the Mediterranean area which would make possible a connection between the easternmost Loran-C station (today Kargaburun in Turkey) and the Chayka station (Simferopol') on the Crimea, thereby ensuring joint coverage of the Black Sea area. Another solution may be to connect the Crimean station to the Italian station on the island of Lampedusa.

5. LORAN-C AND GNSS. As indicated above, Loran-C and satellite systems may be regarded as complementary, particularly for land navigation, where limited satellite visibility at some positions (particularly in cities) may reduce performance below acceptable levels. The availability of signals from a particular Loran-C station is above 99·9 percent and the availability of a chain is above 99·7 percent. Corresponding GPS numbers are lower.

A number of investigations have been undertaken to clarify the benefits of integrating Loran-C and GPS receivers (Reference 3 is one example), especially for land navigation where the really big markets exist. The availability numbers just mentioned clearly indicate that integration would considerably increase the robustness of the navigation system as experienced by the user. Because of the TOE control of transmissions in Europe, each Loran-C transmitter can be used as an extra satellite, thus increasing not only robustness but also improving DOP values.

By continuous calibration of Loran-C (as long as there are enough satellites in view) by means of a differential satellite system, the accuracy of the contribution from the terrestrial system is comparable to that of the satellite system. In a recent research project carried out in Norway,[4] measurements showed that a quality Loran receiver deviates less than 5 m (95 percent) within 2 hours after calibration with DGPS and less than 25 m after 24 hours. The rms noise as measured by two different Loran-C receivers was less than 5 metres (Fig. 1). The background for this project was the requirement by the Norwegian Petroleum

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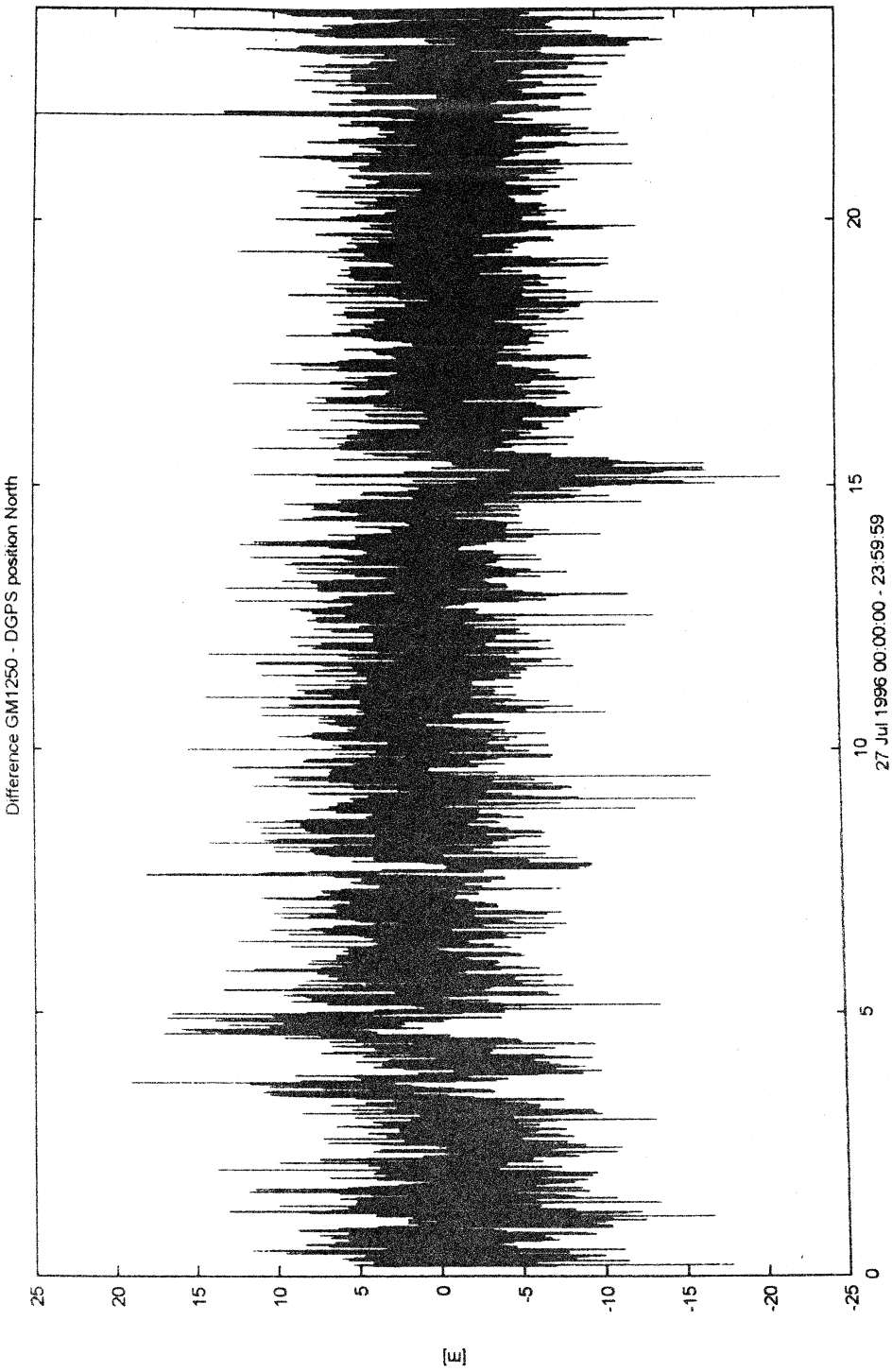


Fig. 1. Difference between calibrated Loran-C and DGPS positions in dynamic measurements at 65° N and 5° E, using the Eide 9007 chain.

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Directorate, in accordance with IMO guidelines, that three independent navigation systems must be used in dynamic positioning operations for drilling and oil loading at sea.

Another very interesting possibility when combining Loran-C and satellite systems is modulating Loran-C signals for communication purposes. This technique has been investigated at the TU Delft (Netherlands) for a number of years and is called EUROFIX. The method involves balanced position modulation of Loran-C pulses and can be used for information transfer at a rate of about 25–30 bits/s. In view of the long range of Loran-C signals, this opens up an interesting possibility for dissemination of differential corrections over large areas. The technique has been tested for dissemination of DGPS corrections in normal operations of the Sylt transmitter with a very positive outcome.[5]

The NELS Steering Committee decided in April 1997 to implement the method on a phased basis in all NELS transmitters. Phase I will be initiated early in 1998, and by the end of 1998 the stations at Lessay (western France), Værlandet (western Norway) and Bø (northern Norway) will be disseminating DGPS corrections.[6] Phase II, i.e. the implementation of EUROFIX in all NELS transmitters, is being prepared and is expected to pass the Steering Committee in the autumn of 1998; implementation could then start early in 1999.

The data rate in EUROFIX may seem low, but dynamic test results have shown it to be adequate for the purpose.[5] EUROFIX will be even more interesting when Selective Availability (SA) is removed from GPS transmissions and could, by then, also include GLONASS corrections. A similar technique is being evaluated in Russia for using Chayka in a corresponding manner.

A fact which should not be forgotten when discussing expanded use of Loran-C is the limited availability of receiving equipment. This fact has also been noticed by CEU representatives in the context of the European Transport Network. For this reason, suitable receiver development in Europe is being encouraged and stimulated. Recently, it was announced[6] that the CEU together with European industry has started funding the development of an integrated Loran-GPS-EUROFIX receiver in an on-going Framework IV programme for integrated bridge systems, called DISC II. It is expected that this will lead to the availability of several receiver types, e.g.

(i) a pure Loran-C navigation receiver;
(ii) a pure EUROFIX receiver for reception and decoding of EUROFIX transmissions and feeding the corrections into some GPS receiver;
(iii) a combined Loran-GPS navigation receiver;
(iv) an integrated Loran-GPS-EUROFIX receiver.

Finally, if Loran-C service is expanded, the system may become a regional facility, similar to the European Geostationary Navigation Overlay Service (EGNOS). If this occurs, there may be a requirement to define a European-wide Loran-C agreement. This could also lead to Loran-C being included in the activities of a GNSS agency.

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KEY WORDS

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