RECENT DEVELOPMENTS OF LORAN-C IN EUROPE

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Summary

Even if recent developments, both technical and political, are affecting the satellite GPS and GLONASS navigation systems, alone, in conjunction, or with a possible civilian overlay via INMARSAT or other satellites, the time proven that Loran-C can be still a viable solution for many problems.

The aims of this paper are twofold, to present a panorama of the most recent developments in the World and mostly in Europe, and to consider some technical aspects of two problems regarding the Mediterranean Sea chain.

This chain is at moment based on four stations, two in Italy, one in Spain and in Turkey. The fate of the station in Turkey is known, in the sense that this station will not operate when the U.S. support will cease; the future of the Spanish station it is not yet known, while Italy has expressed its intention to operate the two remaining stations. Consequently two problems are to be solved if it will be needed to assure at least the coverage of Italy and of the eastern Mediterranean Sea.

1 Recent Developments of Loran-C

Since this paper is unique during this XXIV PTTI Meeting in addressing Loran-C topics, it seems appropriate to present an overview of the recent developments of this navigation system.

In order to avoid misunderstandings, care will be taken by differentiating between *activities underway*, *existing programs* and *tentative studies*.

1.1 America

As regards the American continent, starting from North, **Canada** is taking an active part in the North-European Loran-C Policy Group — to be introduced later in section 2.2.2 — in order to secure, by the possible upgrading of a station, a better coverage of the waters south of Greenland.

A research activity is performed [1] in order to validate, using GPS, the distortion of the Loran-C grid due to variations of the secondary phase factor, for land navigation applications.

In the **U.S.A.**, as it is well known, for mid 1991 it is expected the coast to coast coverage of the continental States.

Along the large industrial production of airborne Loran-C navigators, combined Loran-C/GPS receivers were announced and there are hopes that a suitable combination of GPS with Loran-C could became the sole mean for air navigation in order to abandon, in some future, the system VOR/DME.

Tests were performed on the use of GPS to obtain the Loran-C secondary phase errors [2] for land navigation.

In **Mexico** some studies are being performed in regard to a possible National coverage.

In **Venezuela** a decision was taken to install a national chain with four stations covering the whole Country and its coastal areas with emphasis on the inland waterways, such as the Orinoco river.

In **Brazil**, very preliminary investigations into coverage for the Amazon basin are underway.

No other activities are known in southern America.

1.2 Asia

In Asia, starting from the far east, studies are underway in **Korea**, also with on-field measurements, concerning the upgrading of the two existing stations witch have been take over by Korea, and the possibility to obtain a national chain, with the construction of an additional station.

Japan hosts four stations and, following in some extent the approach of France, is reported to considering the build-up of a national chain, mostly for defense purposes; at any rate the take-over of the existing stations is planned in a few years time.

In **China**, were in the recent years a chain was constructed in the southern part of the Yellow Sea, another chain with three stations is under construction in the northern part of the coastline to complete its eastern coastal coverage. Since some years a powerful Loran-C station (not a chain) is active inland in the Shaanxi province.

Consequently, if Korea will go along with its plans, a continuous coverage will be secured along all the approaches of Asia from the Pacific Ocean.

A **technical working group** has been formed with representative from China, USSR, South-Korea and Japan in order to coordinate present and future Loran-C activities in the area. Chairman of this working Group is the Secretary General of IALA. IALA stands for *International Association of Lighthouses Authorities*, an informal Organization, with seat in Paris, formed by representatives of all the seafaring nations.

As regards **North-Pacific**, it is worth to be noticed the agreement reached on May 1988 between U.S.A. and USSR for a joint operation of their Loran-C/CHAIKA chains in North Pacific ocean and the Bering Sea areas. Following this agreement, to be realized in two steps between 1990 and 1992 a joint radionavigation chain will be formed using stations in Attu, Alaska, Petropavlovsk, Aleksandrovsk, and Kurilsk.

India has decided the installation of two short range Loran-C chains along the eastern and western coast of the subcontinent, to replace the DECCA chains covering the approaches of Calcutta and Bombay.

In the Arabic Peninsula, one of the two existing chains was temporarily turned off before the current confrontation. It is expected to be returned in operation soon.

A short range Loran-C chain is being installed in Dubai, to support a vehicle location system already in operation there, which previously had relied on the Saudi system signals.

In Africa, **Egypt** is keeping in service the low-power Loran-C chain formed by three stations and serving the Suez Canal.

The news gathered in this two sections were collected attending various meetings, or excerpted from the U.S. Radio Navigation Plan (1988 issue), the open literature, the IALA Reports [3,4,5,6,7],

the Volumes of CCIR, the Records of IFRB, the "Wild Goose Gazette" and from conversations with individuals active in the field.

2 European Approaches for Loran-C

2.1 Situation Prior to 1985

The coverage of European waters prior 1985, is reported in every receiver manual, and was based on the North Sea and the Mediterranean Sea chains.

In the late eighties the Ukrainian or Bielorussian CHAIKA chain was officially recorded in the IFRB (International Frequency Registration Board) and CCIR (Comitè Consultatif International pour les Radiocommunications) publications, but the coordinates of two stations only were given at that time:

Briansk	53°13′ N	34°24′ E
Syzran	32°11′ N	49°46′ E

This chain has the GRI of 80.0 ms and is formed by four stations; their signals are well received in our Laboratory, located in North-West of Italy.

The European coverage of Loran-C about 1985 is qualitatively given in Fig. 1.

2.2 Situation After 1985

In 1985, started the activity of two Loran-C stations in France, to be used in the ρ-ρ mode, mostly for military purposes. Obviously these two stations, if operated with the Group Repetition Rate (or with a double rate) of a nearby chain, can constitute a standard hyperbolic Loran-C chain.

The news of the U.S.A. decision to terminate at some time around 1994 the direct or indirect support of the chains operating outside the U.S.A. territories, had meanwhile promoted in 1984, the formation of a North-European Loran-C Working Group, under the Chairmanship of Mr. Steenset, deputy Director General of the *Norwegian Defense Communication and Data Services Administrations* (NODECA). Mr. K. Enerstadt of Norway being the secretary of the Group.

2.2.1 The North-European Working Group

The terms of reference of the Group were:

- to study future requirements for Loran-C chains in the North Atlantic and Norwegian Sea areas,
- to investigate on other navigation options, present or future,
- to study, if Loran-C should be retained, all the relevant technical problems, in the phases of transition and operation,
- to study the organization of future system operation and administration, including chain control and allocation of responsibilities,
- to propose an operation structure, with a relevant budget,
- to formulate proposals about the repartition of the financial charges between the various Nations.

The Final Report, July 1985, concluded with the following recommendations:

1. The present Loran-C system in Northern Europe, should continue to operate beyond 1994.
2. An Organization, as indicated in the Report, should be appointed / established.
3. A Meeting with representatives from the involved Countries should be called to reach agreement as to the formation and term of reference, of the necessary mechanism to have the Organization recommended,
4. Norway should take the initiative to call the proposed meeting.

That Meeting was called in Oslo in May 1987, when a Loran-C Policy Group was formally established.

2.2.2 The North-European Policy Group

The aims of this Group were as follows:

1. To seek agreement between Nations concerned in the continued operation and enhancement of the present Loran-C system in N.W. Europe. Such agreement to include take over of present U.S. Coast Guard Loran-C Stations in the area, utilization of non-U.S.A. stations and Loran-C stations to be established and operation on a cooperative basis.
2. To agree and sign a memorandum of understanding between Governments participating in the System before proceeding with the actual work.

The present membership of this Policy Group with the status of a full member is Canada, Denmark, France, Germany, Iceland, Ireland, Norway, U.K., and, as observer, U.S.A., the Commission of the European Communities in Brussels and IALA.

The Working and the Policy groups meet in total eleven times (the last in Oslo in July 1990, the next in Ottawa in January 1991), and at the moment the text of a Memorandum of Understanding is available and discussed.

2.2.3 Two timing approaches: System Area Monitors, Versus Time of Transmission

Of particular interest for the Time and Time interval community is the fact that the system control, as proposed for the three planned chains, is not based in the traditional *System Area Monitors* (SAM) approach — monitoring stations located in specific points and charged to maintain mutual and internal synchronization of the chain — but on the so-called *Time Of Transmission* (TOT) concept. Following this approach the clocks of all the stations are referred independently to a common reference, such as UTC.

Both approaches, SAM and TOT are equally good in monitoring the transmitters timing errors.

As regards the variations in the propagation delays, SAM enables error minimization, but only in selected areas, while TOT distributes errors more evenly. TOT is more costly in the implementation (more atomic clocks and GPS receivers, but the running cost is less. The TOT approach can present some drawbacks for Time users and Geophysicist, but can provide historical data for delays of propagation.

In U.K., in an official press release in April 1990 of the Department of Transport, it was announced that, at the termination of the public support for the DECCA System, U.K. will participate in the

Loran-C coverage of North-West of Europe sea with a new station in North-East of the Country. This decision will hold if certain considerations will be met. One of these conditions was that Loran-C system should preserve its international flavor and that an acceptable repartition of the charges will be found.

If these conditions are not met, U.K. may reconsider its position.

In the proposals of the Policy Group, is also planned the construction of an additional station in Ireland. This later station, operating with the two French transmitters and with the southernmost station of the North Sea Chain in Sylt, could cover the Channel, the Gulf of Biscay and in general all the western approaches of Europe.

2.2.4 A New Chain in Eastern Europe?

For land and air navigation, some activity is performed Eastern Europe. Indeed a new CHAIKA chain is planned between Eastern Germany, Hungary and Bulgaria; the planned positions of this new proposed chain were:

Eastern Germany	Damgarten	12°27′ E	54°15′ N
Hungary	Esztergam	18°45′ E	47°46′ N
Hungary	Kunmadaras	20°48′ E	47°26′ N
Bulgaria	Pleven	25°04′ E	43°20′ N

No news are available about the status of the new proposed chain nor about the consequences of recent political changes. At any rate it can be stated that, at least from July-August 1990, no activity was observed from our Laboratory at the GRI of 49.60 ms, proposed for the new chain.

2.2.5 An Iberian Chain?

Inside IALA, a small working group, composed by France, Portugal, Spain and U.K. was formed with the task to study the possibility and the interest, with a station in north-west of Spain, or possibly in the Azores, to cover the Portuguese waters and the access to the Mediterranean from the Atlantic Ocean.

A station in Ortegal, in N.W. Spain, with the southernmost French station Soustons and with Estartit, the westernmost of the Mediterranean, double rated, could indeed cover the Iberian peninsula.

The Group should prepare a financial and technical report no later than March 1991, with practical chain configurations, meeting the requirements for Iberian and Atlantic area, including Azores and Canaries.

A possible coverage, for Europe, Mediterranean excluded, is qualitatively given in Fig. 2.

2.3 Mediterranean Sea Chain

Always inside IALA another group, with the chairmanship of Italy, is studying the future of the chain in the Mediterranean area. The membership of this Group includes all the Nation around the Mediterranean Sea, with the exception of Cyprus, Israel, Lebanon, and Turkey .
Concerning the Nations hosting at the moment the chain:

Italy (two stations) has announced in 1988 the intention to assume the operation of the stations when the U.S. support will cease,

Turkey (one station) has announced in 1990, that the service will not continue,

Spain (one station), has not, insofar, announced officially any the decision, but informally, the opinion is that, provided some support will be granted and the operations of the two Italian stations will be secured, the activity of the Estartit station will be extended.

If the above scenario will become reality, two situations are to be considered :

1. if the operations of Estartit station will not secured, Italy will have to make a decision, whether to drop the coverage of Loran-C around Italy, or to form a national chain with the two existing stations of Sellia Maria and Lampedusa and the addition of a third new station,

2. if the coverage of central-eastern Mediterranean must be ensured, another new station in the area must be erected.

The technical aspects only of possible solutions to the two problems will be presented in what follows.

3 A New Transmitter, Where?

As well known, a Loran-C transmitter is to be placed in on an high conductivity soil in order to achieve a reasonable radiated to loss power ratio. This is due also to the dimensions of the practical antennas, that are small compared to the wavelength (3 km); a "small" antenna presents a "low" radiation resistance and consequently the overall resistance of the earth system must be as "low" as possible.

Only a few places with suitable soil conductivity exist in the eastern Mediterranean. Keeping in mind that signal coverage and geometrical dilution of precision requirements are to be met, the set of possible places is further reduced. As regards the Italian solution, more severe constraints arise from the Country shape.

Some hypothesis are considered here and summarized in Fig. 3 and Table 1, in which the approximate considered positions are given, along the existing M, X, Y and Z.

Stations C, T, N or E are proposed as a possible replacement for the Turkish Y.

If a fully national system is indeed to be implemented, V or W can be chosen, in conjunction with the existing M and X. One of these stations was initially proposed as a possible extension of the chain, and a technical study is available [3].

A transmitter located around Genova (north west Italy), as sometimes proposed in [8], has not been considered because of the soil conductivity of the area; moreover, being the region highly populated, it would be very difficult to find a site.

Finally, political consideration, not included here, could still reduce the set of possible sites.

4 Coverage and Related Problems

4.1 Signal Strength

The groundwave signal strength is evaluated for all the proposed and existing stations using a computer program especially written for this purpose. The program is based on the data available in the CCIR report 717-1 [9], converted in a digital map with a resolution of 0.5° in latitude and longitude, and the method therein proposed for mixed paths.

IDENT.	LAT. (deg)	LON (deg)	POWER (kW)	BASELINE (km)	SITE	COUNTRY
M ¶	38.9	16.7	165	n. a.	Sellia Marina	Italy
X ¶	35.5	12.5	325	525	Lampedusa	Italy
Y ¶	41.0	27.9	165	980	Kargabarun	Turkey
Z ¶	42.1	3.2	165	1195	Estartit	Spain
C †	35.2	24.5	165	800	Creta	Greece
T †	40.8	24.6	165	710	North East	Greece
E †	31.5	26.2	165	1190	North West	Egypt
N †	31.2	33.2	165	1725	Nylus delta	Egypt
V ‡	44.5	12.2	165	730	Po delta	Italy
W ‡	45.4	13.4	165	770	North East	Italy
¶ existing			† replaces Y		‡ Italian system	

Table 1: Existing and proposed Loran-C transmitters in the Mediterranean area.

The proposed transmitters are supposed to be quite similar to the existing ones, with the same radiated power and 190 m top vertical monopole; only Lampedusa (Y) is different.

The output of the program is the groundwave electric field for all the transmitters, evaluated at each cross point of a 1° spaced grid for the region 5–35° W and 30–50° N.

4.2 Noise

A single value of the atmospheric noise is adopted in the whole analysis, 47.5 dB over 1 μV/m in a two sided band of 20 kHz. This figure, based on the CCIR report 322-2 [10] and taken from an earlier analysis [3], is evaluated for the point 40° N, 15° E, in the middle of the region shown in Fig. 3. It is the average noise power in the worst case as regards the season (Summer and Autumn) and daytime (00 ... 04 Local Time).

The average value, versus the season and daytime, spans over about 30 dB; upper and lower deciles, in the same conditions, are 10–15 dB apart from the average. In the whole area the variations of the average value never exceed 2–3 dB. The man made noise and the coherent interferences are not considered here.

4.3 Geometry

The relation between positioning and timing errors, known as GDOP (geometrical dilution of precision), involves two concepts:

Sensitivity. Considering two transmitters, the sensitivity S is the ratio of positioning error vector p divided by the timing error t, and is given by $S = c/2 \cos \psi$; S is a vector perpendicular to the hyperbola, c the speed of light, ψ the angle at the receiver site delimited by the direction lines towards the transmitters.

Crossing angles. Being the position obtained as the intersection of two hyperbolae, each generated by a couple of transmitters, its error is the sum of the two vectors given by the sensitivities and the timing errors.

It is a common practice to evaluate the GDOP with a scalar formula, assuming that timing errors are originated by Gaussian white noise, uncorrelated for each time difference.

In our opinion the GDOP should be considered as the sum of two error vectors because the most important sources of errors are the systematic or seasonal propagation effects, that are not white noise. Moreover, the white noises on the two time differences are correlated because one transmitter is common.

5 Two Hypothesis for the Future of the Chain

5.1 A National Navigation System for Italy

A national system, based on Sellia, Lampedusa and W will provide a fair signal to noise ratio, as shown in Fig. 4. Most of the national area lies in the shadowed area, where the evaluated S/N ratio is 10 dB or better. Since most receivers work reasonably with S/N = 0 dB, there is a sufficient margin.

The geometrical dilution of precision is shown in Fig.5, where the module and angle of the sensitivities are plotted for the triad M-X-W.

The extreme north-eastern Italy and a small southern region near the continuation of the line from X to M are not covered because of the sensitivity. In most of the peninsular area the sensitivity spans from 200 to 500 m/ns and the crossing angles are near 90°, which is the best. In a small region, at south west of Sardinia island, the positioning will be difficult because of the crossing angle near 180°, despite of the "good" sensitivity and S/N.

The solution V, not shown, will provide a slightly better signal coverage, but the north eastern blind area will considerably increased and shifted from outside to the Country.

5.2 A Loran-C Coverage for Eastern Mediterranean

In the case that the central-eastern basin of Mediterranean should be covered, four possible sites were investigated: these sites are listed in Table 1 and shown in Fig. 3. In all the cases the criteria of sections 3 and 4 were taken into account.

As regards station C, in the north coast of Crete island, there are some flat lands along the sea side , the same conditions are met for station T planned in the North-East border of Greece, about 230 km West of the present site of Y station.

The two proposed sites in Egypt were chosen with the following criteria; the eastern site in order to cover most of the eastern basin of the Mediterranean, the western one because the former "Egyptian" site would require an high power transmitter, being the baseline with the master of about 1700 km.

The investigations about geometrical and signal to noise problems, were repeated for all the proposed sites, using as a Master the present one.

From the investigations, it seem that the best site is C, on the island of Crete, because the resulting baselines are adequate and the geometry of the first Mediterranean Sea chain — before the shift of Matratin station in Libya to Lampedusa — is somehow restored.

In Fig. 6, for this latter solution are given the plots of constant signal/noise ratio, including the existing M and X. In the shadowed areas, the sensitivities are less or equal than 600 and 1000 m/μs.

From the results of this study, it can be pointed out that with only one additional station both of the problems cannot be solved.

Obviously, if the new proposed chain in Bulgary and Hungary will became a reality, the problem should be fully reconsidered.

6 Final Remarks

It must be stressed that in this analysis nor economical nor political considerations were taken in to account.

Moreover, this research was supported by University founds only and no implication must be made about a possible construction of any of the considered stations.

Political considerations apart, it can be stressed that Loran-C still provides an useful service and that is to be considered as an economical solution when a regional navigation service must be provided.

References

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[8] E. Rubiola, "A possible extension of the Mediterranean Sea Loran-C chain," in *Proc. NAV 88, Radionav 2000 — a European Dimension*, Conference of the Royal Institute of Navigation, London (UK), 22–24 March 1988, paper no. 22.

[9] "World atlas of ground conductivities," CCIR report 717-1, Dubrovnik 1986.

[10] "Characteristics and applications of atmosferic radio noise data," CCIR report 322-1, Dubrovnik 1896.

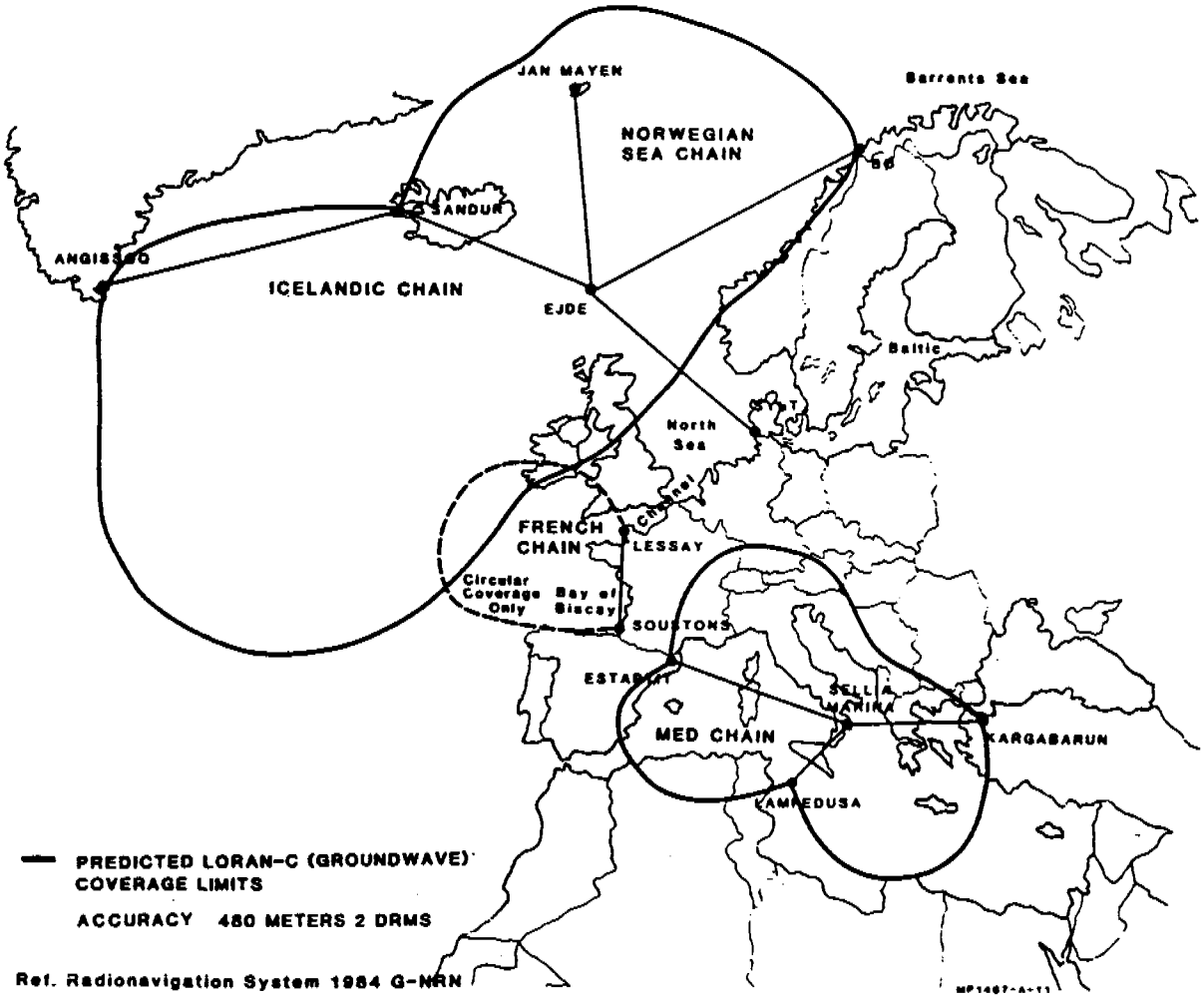

Figure 1: Loran-C european coverage in 1985.

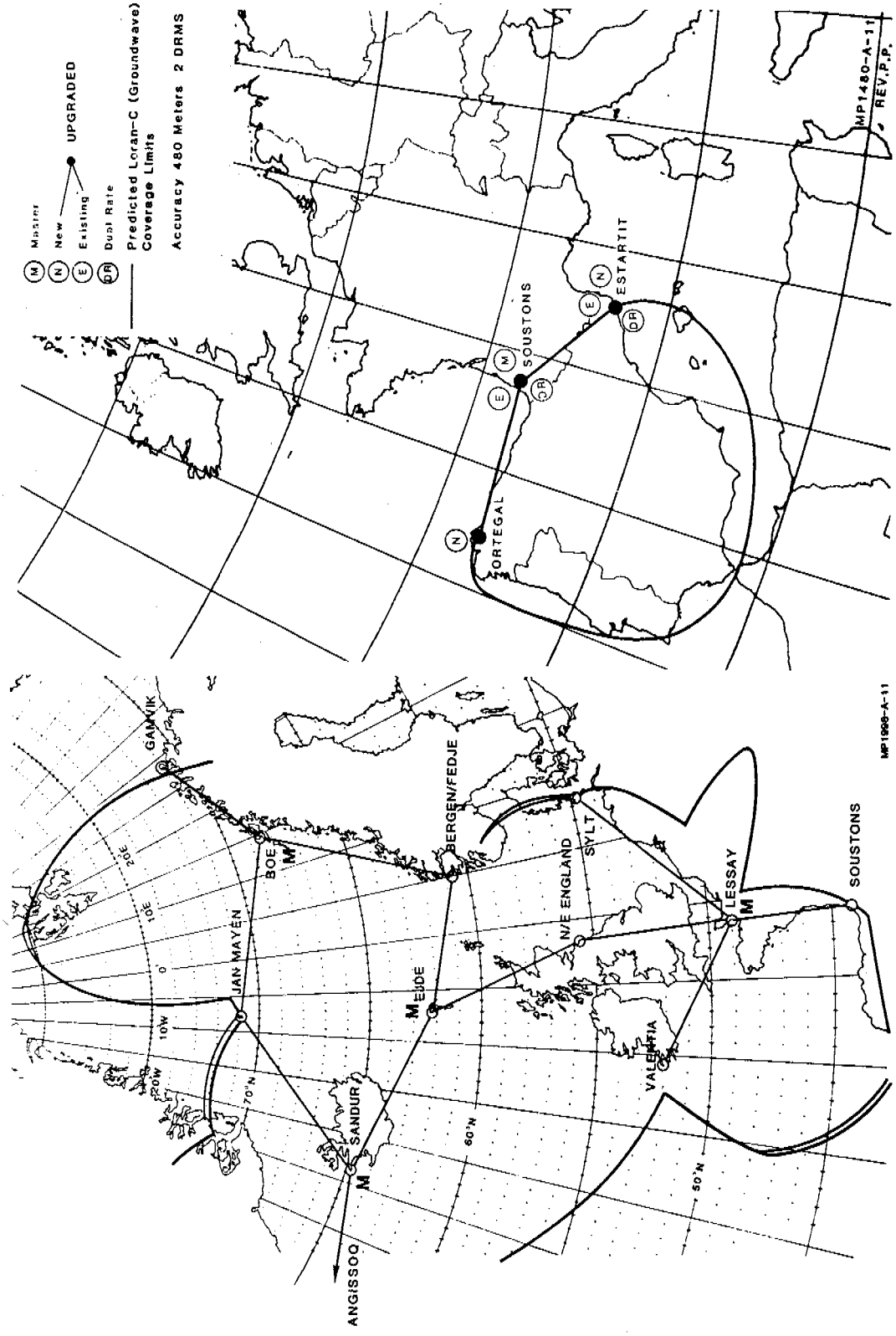

Figure 2: Loran-C european possible coverage about 1995

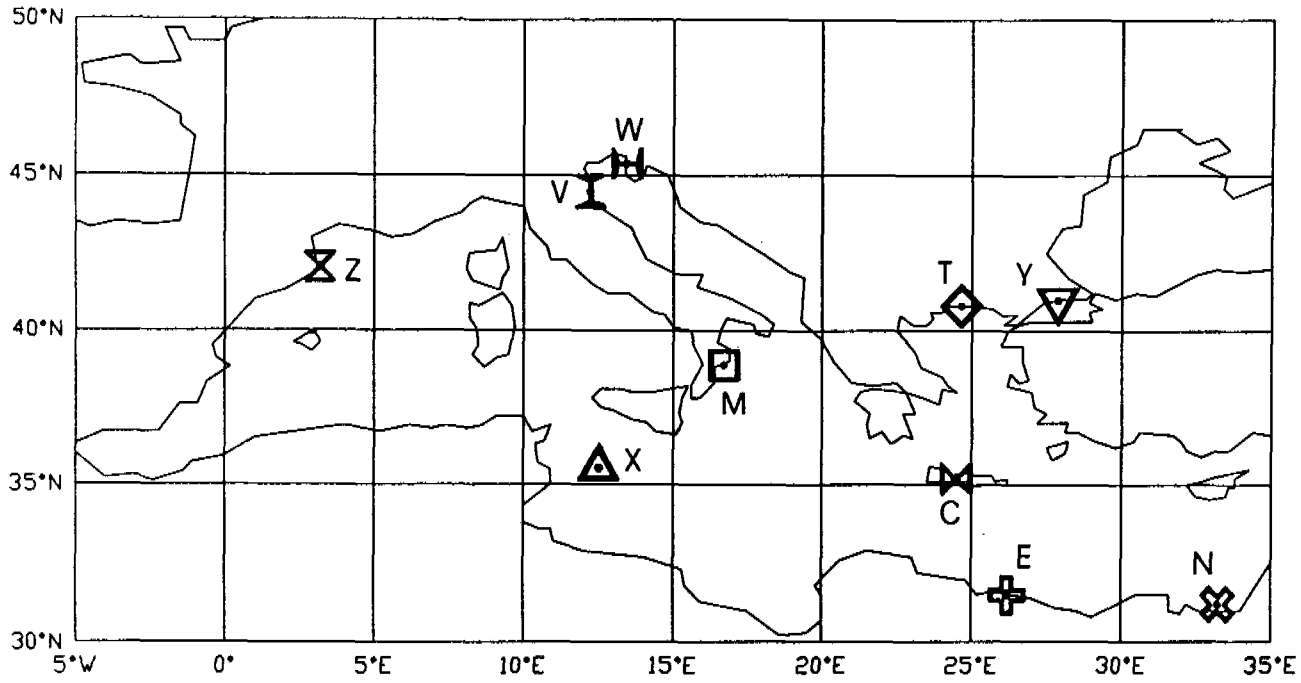

Figure 3: Existing and proposed Loran-C transmitters in the Mediterranean area.

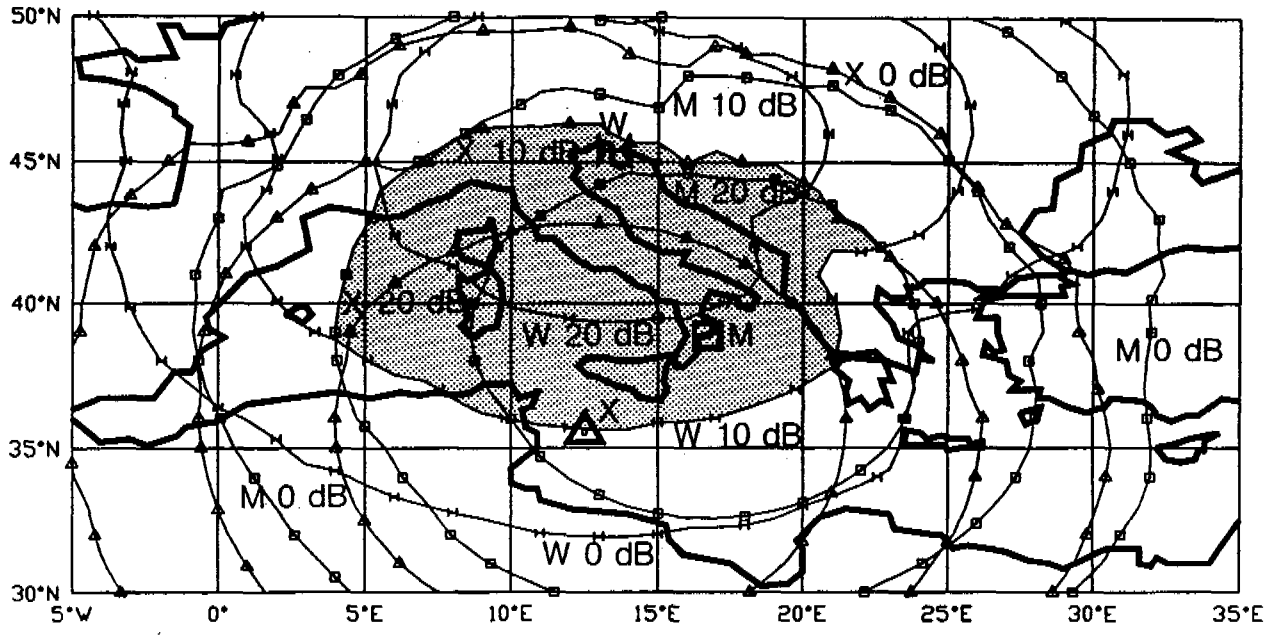

Figure 4: Calculated S/N ratio for the hypothesis of an Italian national system in which the station W is added.

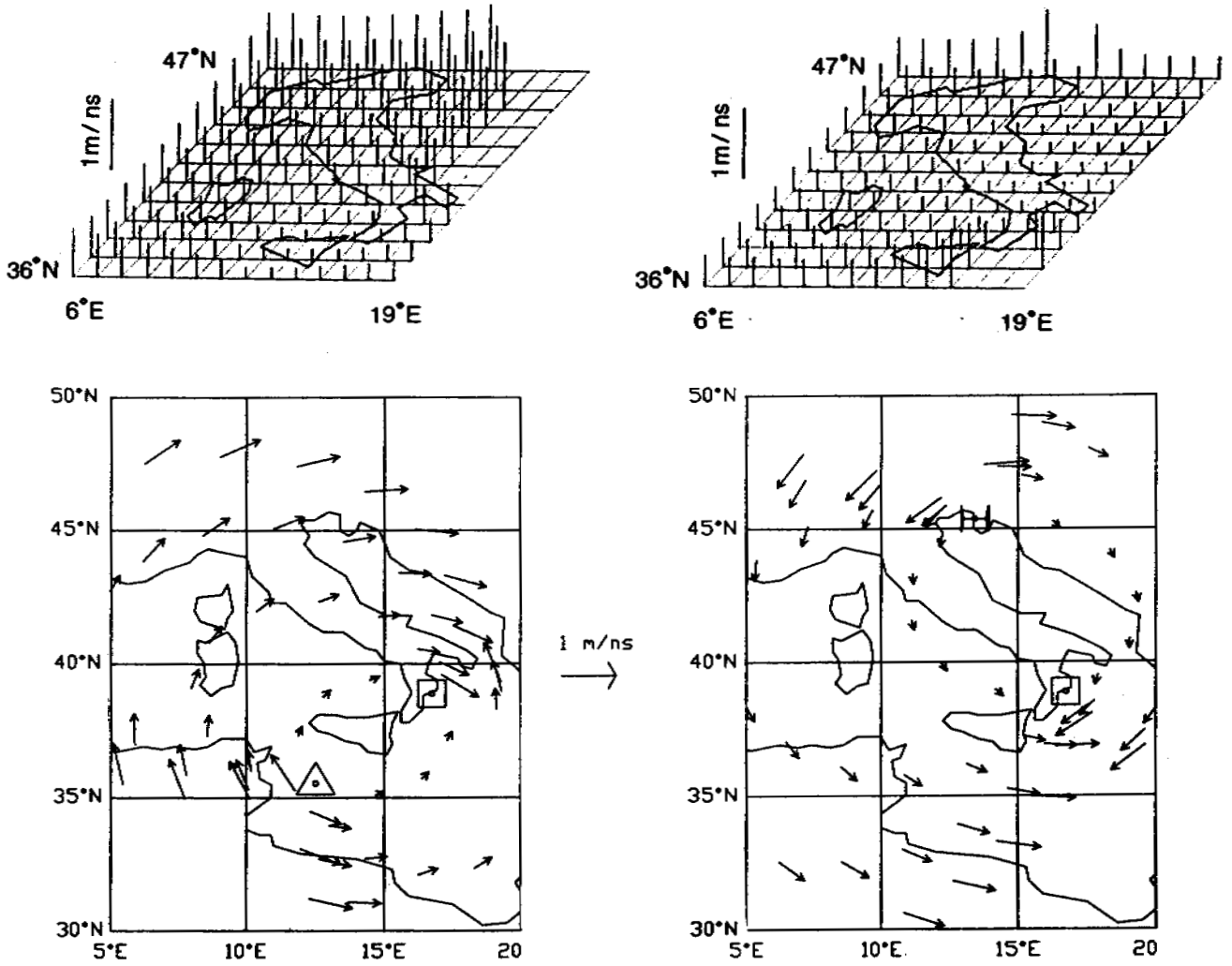

Figure 5: Sensitivity for the stations M, X and W. **Top:** module, the reference segment is 1 m/ns; all the values above 1.2 m/ns are suppressed. **Bottom:** angles; they are not distorted as the map.

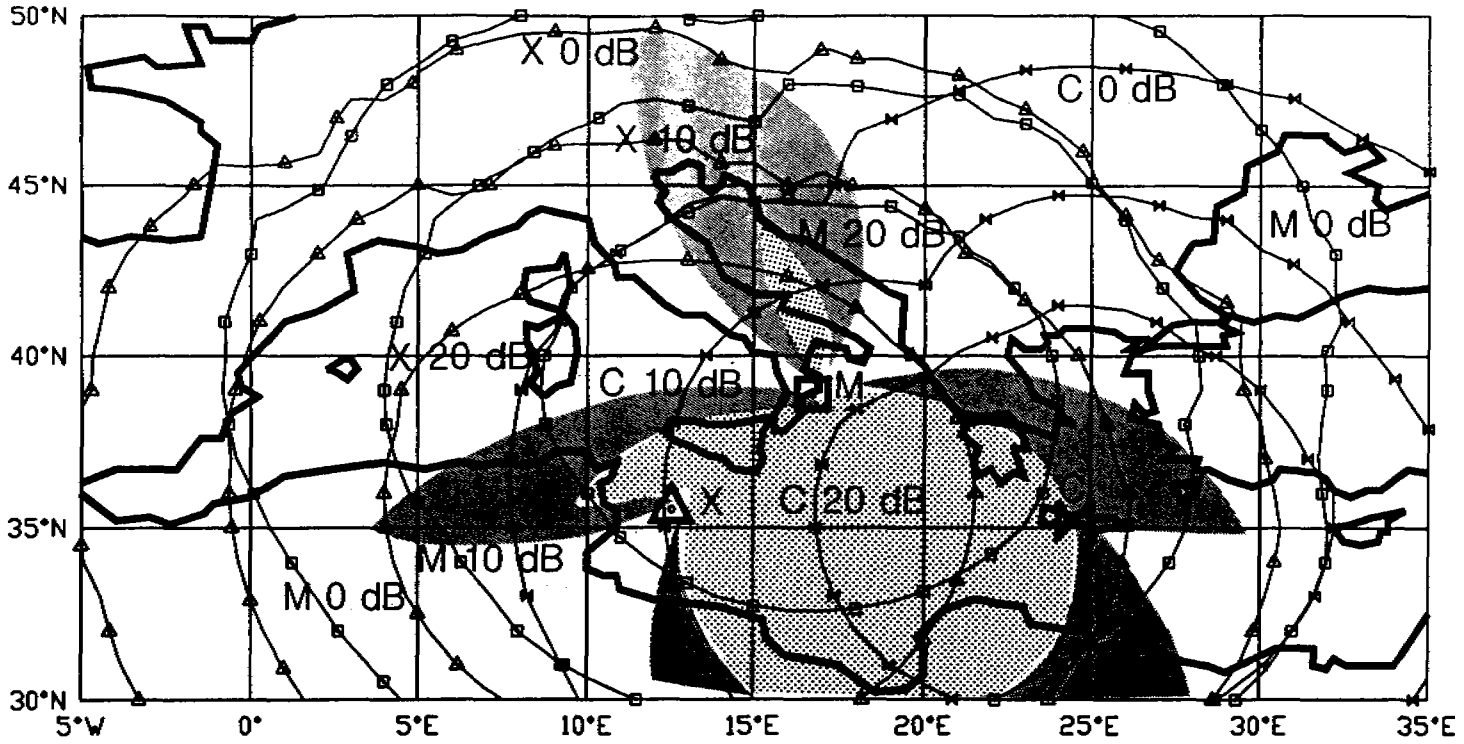

Figure 6: Geometrical and Noise limited coverage for a possible eastern Mediterranean chain, with a slave in Crete.

QUESTIONS AND ANSWERS

Unidentified Questioner: I understand that this band from 90 to 100 kiloHertz is allocated differently in Europe than it is in the United States.

Professor Leschiutta: You are completely right. That is a problem, but it can be solved. I am not speaking about metrological use, but about those who are interested in navigation.