

Loran-C Coverage of the East Mediterranean

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Abstract

This paper will present a technical study of some possible developments of the Mediterranean Loran-C chain after the end of 1994, when the U.S. support will cease.

Some alternative solutions are studied, with an evaluation of the S/N ratio and GDOP for a few new sites suggested by a preliminary selection. The coverage based on master-independent and crossed-chain operations are also considered.

1 Introduction

The Mediterranean Loran-C chain, in its current configuration, consists of four stations, two in Italy (M and X), one in Turkey (Y) and one in Spain (Z). While agreements are in progress, supported by official decisions, in order to keep in operation stations M, X and Z, when the U.S. support will cease, station Y could be switched off after the 1994 deadline. The consequence would be the unavailability of the system in the eastern Mediterranean, about half of the present coverage.

The aim of this paper is to analyze a few alternative solutions for replacing the Y station with a new one, in order to ensure the coverage of the eastern Mediterranean area. The link to the Russian Chayka is also considered.

Some geographical and technical criteria concerning the site choice are discussed in the next section. The evaluation of signal-to-noise ratio and geometric effects are presented in sections 3 and 4. Results are discussed in section 5, in which the possible new configuration are presented together

with some possible improvements based on master-independent and crossed-chain operations.

2 Proposed Sites and Existing Stations

As well known, a Loran-C transmitter is to be placed in an high soil conductivity site. This is due to the ground wave propagation behaviour and to the radiation efficiency, which relies on the ratio of radiation to grounding resistance. Practical antennas are small (200 m) compared to the wavelength (3 km), thus showing a "low" resistance; consequently, the overall resistance of the grounding system should be kept as small as possible, thus excluding many places.

When geometrical considerations are included (i.e., baseline length of 800–1200 km and angles between baselines of 60°–90°, hardly suitable to the Mediterranean shape), only a few convenient locations remain. Political considerations, not taken into account, could furtherly reduce the set of sites.

Some places are considered here, summarized in Fig. 1, together with the existing transmitters sites.

Stations M, X, Y and Z constitute the Mediterranean sea chain in its current configuration. Their powers have a conventional value of 250 kW, which is in agreement with the decisions taken for easy comparison between results by the Working Group set by IALA in order to discuss these problems [1]. The actual power of these transmitters [2] is 1.8 dB lower than stated except for X, which is 1.6 dB stronger.

Transmitter U is a part of the Russian Chayka

IDENT.		LAT. (deg)	LON (deg)	POWER kW		BASELINE (km)	SITE	COUNTRY
M	¶	38.9	16.7	250	†	n. a.	Sellia Marina	Italy
X	¶	35.5	12.5	250	†	525	Lampedusa	Italy
Y	¶	41.0	27.9	250	†	980	Kargaburun	Turkey
Z	¶	42.1	3.2	250	†	1195	Estartit	Spain
C	†	35.2	24.5	250		800	Creta	Greece
T	†	40.8	24.6	250		710	North East	Greece
E	†	31.5	26.2	250		1190	North West	Egypt
U	¶	45.0	34.0	550		1580	Simferopol	Russia

†replaces Y ¶ existing ‡conventional value

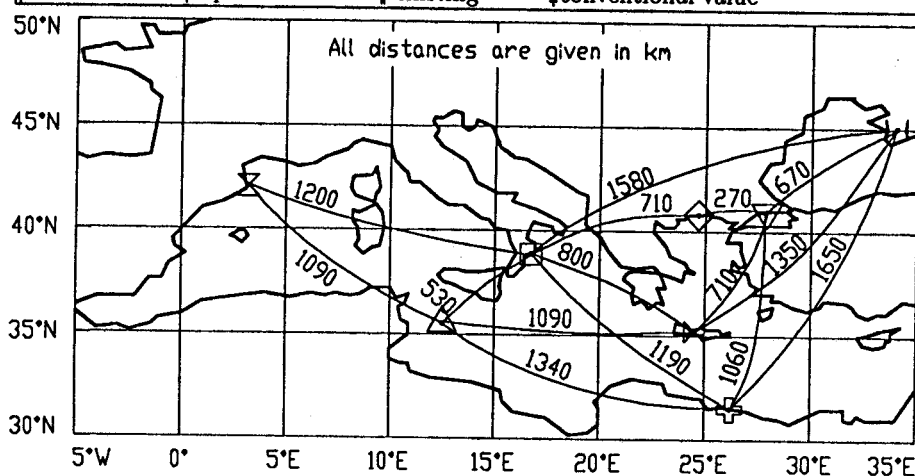


Figure 1: Existing and proposed Loran-C transmitters in the Mediterranean area.

chain. Its approximate coordinates have been derived from a map published in a IALA report [3]. The actual power (550 kW) has been used in simulations. If the Simferopol transmitter could operate in double rate mode, or if it could be used by multi-chain receivers, it could contribute to the Mediterranean chain.

Stations C, T in Greece or E in Egypt are proposed as possible replacements for the Turkish station Y. The proposed stations are assumed to be based on the new solid state transmitters (250 kW) with 190 m top loaded monopole antennas, similar to the existing ones.

As pointed out by the IALA Technical group [4], four stations are not sufficient for full coverage of the Mediterranean sea. If station Y were kept in operation, E appears to be a good candidate to improve the coverage of the eastern Mediterranean. Under this hypothesis, links to Chayka, through Y, and to the Egyptian chain, through E, are worthy of consideration.

3 S/N Ratio

3.1 Noise

An earlier analysis [5], based on the CCIR reports [6] showed that in a central point of the Mediterranean area, and in the worst case for season and daytime (Summer and Autumn, 00-04 local time), the average value of the atmospheric noise is 47.5 dB/($\mu\text{V}/\text{m}$) in a 20 kHz band centered around 100 kHz. Depending on season and daytime, the average noise spans in a range of 35 dB; upper and lower deciles depart from the average values by 10-15 dB. When considering the whole Mediterranean sea, the noise level is substantially the same as for the central point, with differences within than 2-3 dB.

The U.S. Coast Guard coverage map [7] for the Mediterranean sea chain is based on the assumption of a noise level of 51 dB/($\mu\text{V}/\text{m}$).

For north-western Europe, in quite similar conditions as regards the atmospheric noise, it was suggested [8] that the combined effect of coherent inter-

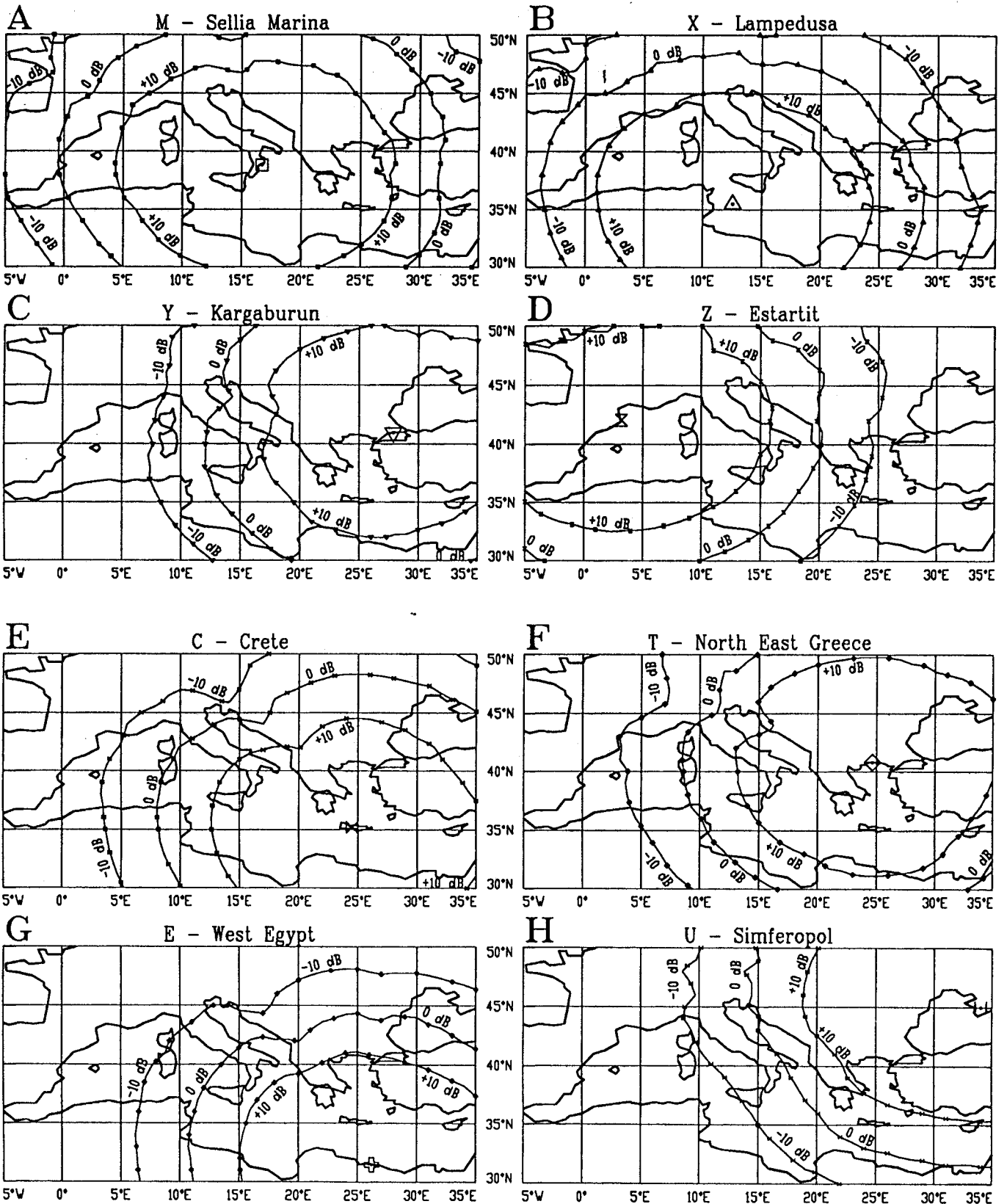


Figure 2: S/N ratios for the existing and proposed stations.

ferences and atmospheric noise can be represented by a field strength of 61 dB/($\mu\text{V}/\text{m}$).

In agreement with the suggestion of the IALA Loran-C Working Group [1], a conventional value of 50 dB/($\mu\text{V}/\text{m}$) has been used in this work.

3.2 Signal Strength

The main source of information is the CCIR report 717 [9], which provides maps of ground conductivities, attenuation curves for uniform soil paths, and a clear explanation of the evaluation algorithm for mixed paths, based on the Millington method.

The CCIR maps are stored in a disk file as a matrix representing the Mediterranean area quantised in 0.5° wide regions, both in latitude and longitude. The conductivity quantisation is the same as for the CCIR maps, in steps of a factor of three from 10 $\mu\text{S}/\text{m}$ to 30 mS/m for the ground, plus 5 S/m for the sea.

Excluding Italy, where a very accurate study is available [10], some doubt still remain about the accuracy of some of the CCIR maps and about the availability of detailed maps for other European zones.

A computer program evaluates the propagation attenuation from the transmitter to all of the points on a $0.5^\circ \times 0.5^\circ$ grid. The attenuation is combined with the radiated power, thus providing a matrix of signal strengths.

3.3 Results

The electric field matrix is combined with the noise by a program which converts results in Autocad *script* format. Results are shown in fig. 2 as curves of equal S/N ratios for +10, 0 and -10 dB.

A comparison with some measurements performed in Spain was done during a meeting of the IALA Mediterranean Loran-C Working Group [11]. Experimental values agreed to the calculated ones within 0 to -3 dB if the whole wave path is over the sea, while the measured S/N ratio was lower by about 10 dB if waves cross long land paths.

Taking into account the sensitivity of the new receivers, which work with S/N ratios as low as -10 dB, and some possible corrections to calculated S/N ratios, the stations should ensure a good coverage

inside the area where $S/N \geq +10$ dB, and a fair coverage as far away as the 0 dB curve.

4 Geometric Dilution of Precision

When the position is derived from time difference, timing errors produce position discrepancies. This is the well known problem of geometric dilution of precision (GDOP), which relies on the following concepts:

1. When considering two transmitters, which originate one hyperbola at the receiver site, the sensitivity S is given by the ratio of the positioning error vector p divided by the timing error t . S is a vector perpendicular to the hyperbola, whose modulus is given by $|S| = c/(2 \sin \alpha)$; c is the speed of light, and α is the angle at the receiver site between lines directed towards the transmitters.
2. Since the position is 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 sensitivities and timing errors.

When adding error vectors originated by time jitter, the standard deviation of the evaluated position is constant on an ellipse. The excentricity of the latter depends on the angle between the two hyperbolae. Errors due to time biases, i.e. errors originated by the finite conductivity of the ground, can also be added as vectors.

In this work the geometric errors have been evaluated as the 95% probability position uncertainty radii ($2d_{\text{rms}}$) assuming a unique value of the time jitter ($\sigma = 100$ ns). In this way the geometry is evaluated separately from the signal to noise ratio. The uncertainty radius is given by

$$2d_{\text{rms}} = \frac{2k\sigma}{\sin \gamma} \sqrt{\frac{1}{\sin^2 \frac{\alpha}{2}} + \frac{1}{\sin^2 \frac{\beta}{2}} + \frac{2\rho \cos \gamma}{\sin \frac{\alpha}{2} \sin \frac{\beta}{2}}}$$

where:

k is the half speed of the light, about 150 $\text{m}/\mu\text{s}$,
 γ is the angle between the two hyperbolae,

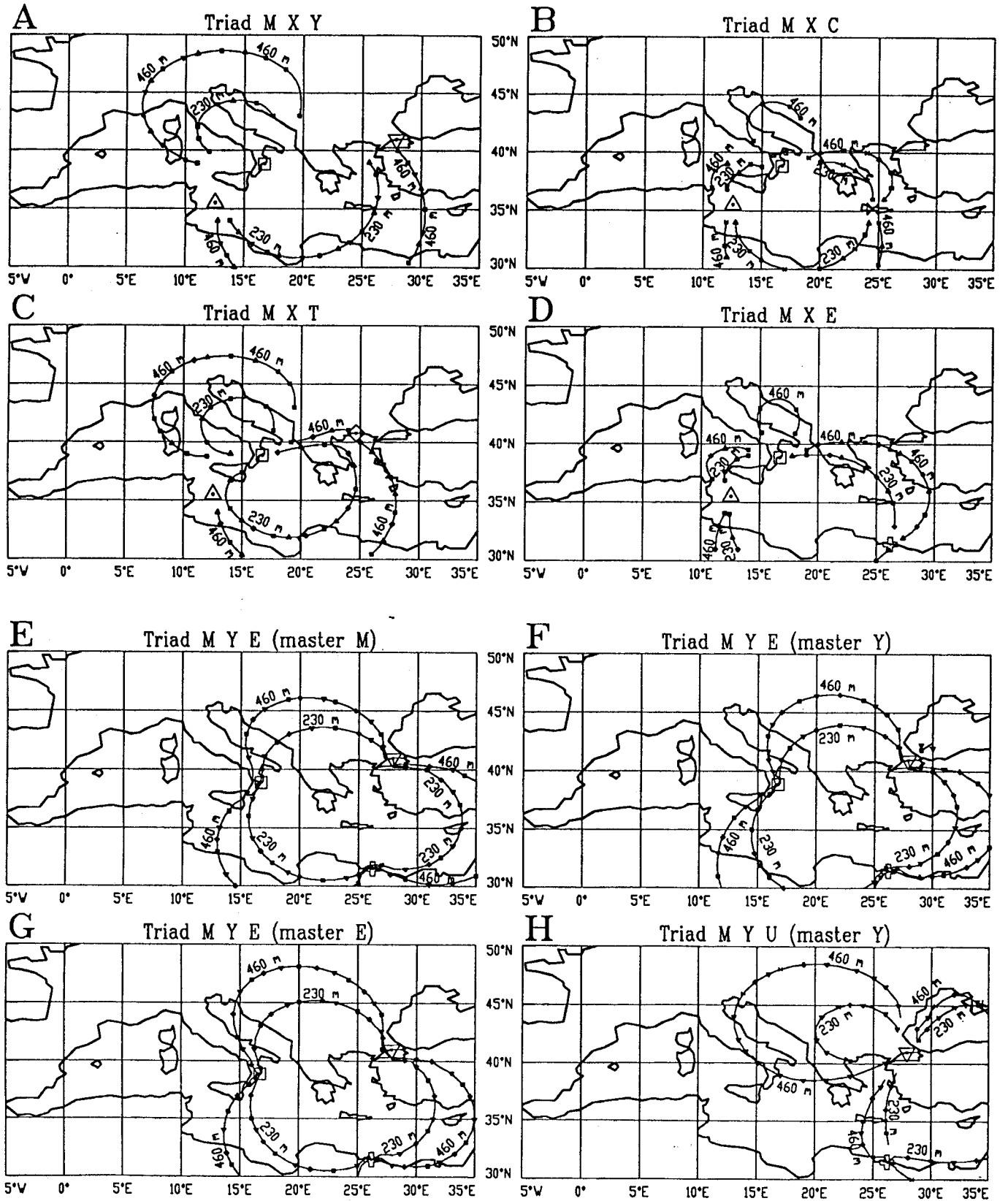


Figure 3: Geometrical dilution of precision for the existing and proposed triads.

ρ is the noise correlation between noise contributions of the two time differences, each one generating an hyperbolic locus of position. Since propagation time for the master station is the same for the two hyperbolae, then $\rho = 0.5$, α and β are the angles between lines joining the receiver to master and each of the secondary stations, σ is the standard deviation of the time differences measured by the receiver.

Results are reported in Fig. 3, where the areas within curves represent position uncertainty radii ($2d_{rms}$) less than 1/4 nm (460 m) and 1/8 nm (230 m).

5 Coverage

In this section the coverage of the proposed chains is presented. Assumptions are that the S/N ratio should not be less than 0 dB and that the consequence of a 100 ns time jitter should be a position uncertainty smaller than 1/4 nm, or 460 m.

In the present system configuration the eastern coverage is based on stations M, X and Y. Comparing figures 2 A, B and C, availability of signals is seen limited in the east direction by station X. This limit can't be overcome by replacing Y.

Comparing figures 2 B (S/N Y) and 3 A (geometry M-X-Y), the most important limitation can be seen to arise from the S/N ratio of station X.

All of the proposed stations ensure a good S/N ratio coverage in all the east Mediterranean area (Figs. 2 E, F and G).

When analyzing new chain configurations, the south Adriatic is worthy of consideration because it is not covered at the present time. This lack of coverage is due to the M-X baseline direction, and it can't be overcome by simply replacing the Y station.

5.1 Replacements for Y

5.1.1 Crete (C)

The eastern coverage is limited by geometry, as results from the GDOP plot of Fig. 3 B. The system is almost useless in hyperbolic mode at longitudes farther east than 25° E.

As regards the central-eastern Mediterranean, the C station ensures higher S/N ratios than Y (see Fig. 2 C and D).

5.1.2 North East Greece (T)

When replacing the Y station by T, the baseline direction remains about the same, its length is reduced by about 30%. Consequently, small changes in the GDOP are foreseen (Figs. 3 A and C); the main difference is the loss of 3° of longitude in the region between Crete and Cyprus. However, by taking into account also the S/N limit of X (Fig. 2 B), this loss of coverage is seen to be smaller than what results from the geometry.

5.1.3 West Egypt (E)

Transmitter E ensures a good geometry in the east Mediterranean, farther than the limit due to the S/N ratio of the X station, as results from Figs. 3 D and 2 B. Consequently, this solution allows the present coverage to be kept.

5.2 Improved Chain

The eastern coverage of the system could be improved by adding station E, without switching off Y. Sites C and T are not considered because of baseline lengths, as results from Fig. 1.

By adding station E, the coverage is based on the triad M-Y-E, thus overcoming the eastern S/N limit due to X, which is replaced by the limit of M (Figs. 2 A and B). The stations Y and E ensure a good S/N noise in all the eastern Mediterranean (Figs. 2 C and G).

By comparison of Figs. 2 A and 3 E, the eastern coverage appears to be limited by the M S/N ratio. An improvement of 5° in the east direction is achieved with respect to the present situation. The coverage of the south Adriatic is also ensured, as results from Fig. 3 E.

The adoption of master-independent receivers allows a better use of the triad M-Y-E (Fig. 3 E, F and G). A fair coverage of the region around 30°-35° N, 12°-15° E, which is on the M-X baseline extension, is possible when Y plays the master role. The best GDOP in the south Adriatic area is achieved by using E as the master.

A multi-chain receiver can take advantage from the Simferopol signals. The triad Y-E-U ensures good S/N ratios in the whole east Mediterranean (Figs. 2 C, G and H), even farther than the maps limit. An optimum GDOP is ensured when using

this multichain triad in the eastern Mediterranean, as results from Fig. 3 H.

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