Some Considerations on Loran-C AMV Systems

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Summary

The use of hyperbolic radio navigation systems on ground is developing, but a number of problems are to be solved. A research on Loran-C use in North Italy is under way and some specific points, such as the long term phase and amplitude stability, the short term phase anomalies and the amplitude of positioning errors, are investigated. The first results on these three topics are presented.

1 Introduction

The recent introduction of full automatic and inexpensive navigation receivers has considerably widened the application of positioning devices to vehicles. A number of solutions that are either fully autonomous or based on external aids or finally follow an ‚hybrid' approach, were recently proposed or are commercially available.

One of the most attractive solutions for its characteristics (existing networks, free access, wide area service, and extensive experience for nautical purposes) is based on some hyperbolic navigation radio aids.

Nevertheless, the use of these systems, on ground, poses some problems, namely the propagation delays due to the soil conductivity, the propagation anomalies, and the poor signal to noise ratios encountered in towns or industrialized areas.

The aim of this paper is to address some of these points, and particularly to the uniformity in time and space of the so-called 'error mapping' technique, i. e. the usefulness of the experimental propagation corrections that can be derived by the measurement, in fixed and known points, of a navigation aid reading. An analysis on these topics as regards the Loran-C, is being performed in North Italy, in and around the town of Torino, by the Department of Electronics of Politecnico di Torino, the first results are herein given below. The reader is supposed to be familiar with the Loran-C system and applications, at any rate a recent and excellent review paper is available [1], in which also some speculations concerning the future of the service and an exhaustive bibliography are presented. In the next section the long-term phase and amplitude stability are investigated, the experimental set-up and the bench-mark used as a spatial reference, are described. The third section is devoted to some statistics on the 'cycle identification slippage', as observed using commercial receivers and finally, in the last section, some news are given concerning the amount and direction of the position-error vectors, as measured experimentally on the field, using an instrumented van.

2 Long term phase and amplitude stability

2.1 The bench-mark and the instrumentation used

For the Loran-C phase and amplitude stability measurements, the bench-mark of the Istituto Elettrotecnico Nazionale in Torino was used. The position, firstly obtained via a topographic survey plus a satellite measurement using a TRANSIT receiver, was evaluated by the Doppler technique on the same TRANSIT satellites, during a campaign in which about twenty European Laboratories were involved. In this exercise, the translation method and the so-called 'precision ephemerides' were used [2].

More recently, a new position determination of the same bench-mark was performed [3] using five satellites of the GPS system. The results, both for TRANSIT-Doppler and GPS measurements, are given in Table I, the accuracy is more than adequate for the purposes of this research being the uncertainties less of about 10 meters, both for latitude and longitude for the expeditious GPS measurement and 0.5 meters for the Doppler data, both with reference to the WGS-72 coordinates.

Table I
Bench-mark Position (WGS-72)

	TRANSIT Doppler		GPS	
Latitude	45° 00′	53.78″	45°00′	53.77 (7)″
Longitude	07° 38′	20.05″	07°38′	19.79″

Phase and amplitude measurements were performed using an especially built receiver [4] and three Austron 2 000 receivers, tracking Sellia Marina, Lampedusa and Estratit stations, the master and two slaves of the Loran-C Mediterranean Sea chain. Data are available for a period of about ten years for phase and five years for amplitude.

For some time, a fourth receiver was monitoring Targa Barun, the third slave of that chain, or Sylt, the most southern station of the Norwegian Sea chain. The above mentioned receivers are designed mainly for time keeping purposes and were used for that application, but in our case, these devices offer the advantage to follow separately each Loran-C station. Moreover, with these receivers it is possible to know at what cycle the device is locked and to measure the relative amplitudes of each cycle inside the received pulse. Data are recorded on strip chart recorders, using as reference a number of atomic frequency standards.

To check the evaluation of the propagation delays made using the maps of soil conductivity for Italy [5], two trips with atomic portable clocks were performed between Torino and the Master Station in South Italy and one to Estartit in Spain. In one instance, a continuous Loran-C monitoring of Sellia station was made during the trip all along Italy, for a span of about 1 000 km, since an atomic clock was on board of the van, combining phase and distance measurements, the propagation delays were monitored and the "electrical" position of the antenna of the Master station was derived. The location of the Torino area with reference to the base lines of the Mediterranean Sea Loran-C chain, is given in Fig. 1.

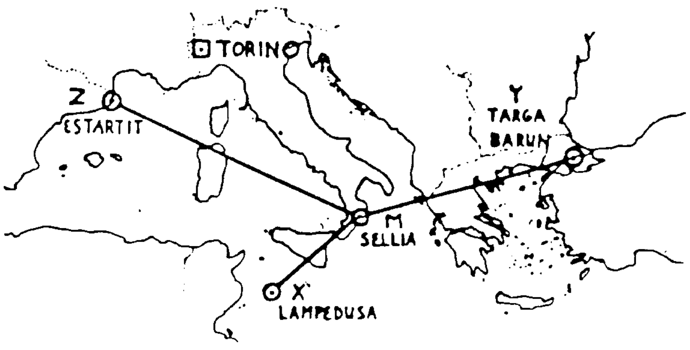

Fig. 1: Mediterranean Sea Loran-C chain

In order to remove the integrated phase effects of the frequency differences between the clock at the Loran-C Master station and the clocks used in Torino, that coincide with UTC(IEN), the italian atomic time scale, attention was given to the following sources of information:

- U. S. Naval Observatory (USNO) bulletin 4. This weekly bullentin contains, with a resolution of 100 ns, the daily error estimates of the clock of the Master Loran-C stations with reference to the USNO Master Clock and finally with reference to UTC (USNO), the atomic time scale of the United States,

- Bureau International de l'Heure (BIH), Circular D. This monthly bulletin contains, with a resolution of 0. 1μs, the daily value of UTC(USNO) – UTC(BIH) and UTC(IEN) – UTC(BIH).

2.2 Phase and amplitude anomalies

Loran-C phase and amplitude records carry a number of information pertaining to different fields, such as radioprogagation, time and frequency metrology and obviously radio navigation, in both aspects, the running of the service and the use of the signals. In the following, attention is paid to the last aspect only, i. e. to the phenomena, regardless their origin, that can impair an accurate radio positioning. Phase and amplitude variations can be intentional, but man-made not intentional, or due to the propagation.

In the first category falls the occasional retuning of a single Loran-C station. Phase jumps of 0.1–0.2 μs can be observed, with variations in amplitude less of 1 dB. For the widespread use of Loran-C signals in international time keeping, some Loran-C pulses are kept in coincidence with a second pulse of the UTC Time Scale, the so called 'Time of coincidence' (TOC). This requirement is met by rare (once or twice per year) corrections in the clocks of the stations. These coordination jumps can be of the order of a few microseconds and are duly recorded in the abovementioned USNO bulletins. These corrections should not be noticeable for the navigation service, since in principle the phase jumps are introduced at the same time in all the stations of a chain, but the experience tells that in these occasions some phase anomalies can occur.

If the signals are weak (i. e. paths of many hundreds of kilometers) and during the night, mostly in winter, a sort of coherent beating (i. e. a sinusoidal-like pattern), can affect the phase.

The peak amplitude can reach 0.6 μs, with a periodicity of 10–15 minutes. The amplitudes are usally between 0.2 and 0.4 μs, with a general rule that a bigger amplitude corresponds to a weaker signal. These anomalies are somtimes coherent, i. e. their 'phase' is the same for all stations (and consequently with no troubles for the radionavigation), but in some cases the beatings are reversed, with damage to the time differences used in hyperbolic navigation.

In many cases, the same coherent sinusoidal variation can be seen in amplitude, with a peak variation of about 0.5 dB. The regularity, as amplitude and duration (some hours), of these phenomena should infer a man-made origin, due to interference with other stabilized carriers.

The most irregular anomalies are due to propagation phenomena and mainly to noise and weather effects.

In not perturbed conditions (usually in daylight and spring to autumn months), the short term (100 second integration time) phase standard deviation is between 30 and 50 ns for the individual and strong signals (X and Z stations).

The peak values, always in these conditions, are typically 0.1, 0.2, and 0.4 μs, respectively for Z, X and M stations, as received in Torino. During the night, these values rise to 0.2, 0.4 and 0.6 μs respectively. The duration of these anomalies is between 10 minutes and a few hours.

In severe storm conditions (for instance an event on February, 11 th 1980, the phase anomaly lasted for about 1.5 h and the peak phase deviations from an uniform trend, were 1.8, 0.6 and 0.2 μs, for M, X, and Z stations respectively. The storm was located in South Italy, since the path from Estartit was not affected.

In not perturbed periods, the phase fluctuations during the night also tend to their daily value and the long term of phase and amplitude trends are remarkably uniform. In some cases the phase track was never lost for many months and, occasionaly, for some years. The amplitude too usually remains stable on long term, well inside ± 1 dB.

The phase is so uniform that frequency departures of few units of 10^{-13} between the clocks of the Loran-C station and that used as a local reference can by easily measured. The long term (some months) frequency departures between the individual Loran-C stations of the same chain are kept inside $\pm\ 1-10^{-13}$ and this is really a good technical achievement, for which the Agency that runs the stations should be congratulated.

To summarize:

- The long term phase and amplitude stabilities are adequate for the application that are envisaged here,
- man-made and natural phenomena affect severely the weaker signals, consequently it is of order a previous choice of the signals to be tracked,
- The propagation anomalies are not necessarily correlated between the various paths and can be, in some specific occasions, very large (2 μs on an individual signal), consequently a differential Loran-C approach can be envisaged when the utmost accuracy must be sought for,
- the simultaneous occuring of large propagation anomalies and of an intentional phase correction is quite unlikely, because the former arrive usually during the night and the latter during the central part of the day.

3 Cycle slips phenomena

Since the focus of the research presented here is on the performance of the commercially avalable receivers, a selection was made over about 25 devices, keeping in mind the following guidelines:

- Power requirements less than 20 W,
- volume less than 5 cubic decimeters,
- conversion of the Loran-C data in geographic coordinates,
- available digital output, with a format compatible with desk-top computers,
- costs less than 5 000 US dollars.

Out of 25-odd models, four were found to fulfil all these requirements, the tests were eventually performed with three sets of different makers. The measurement set-up can assume the form of Fig. 2.

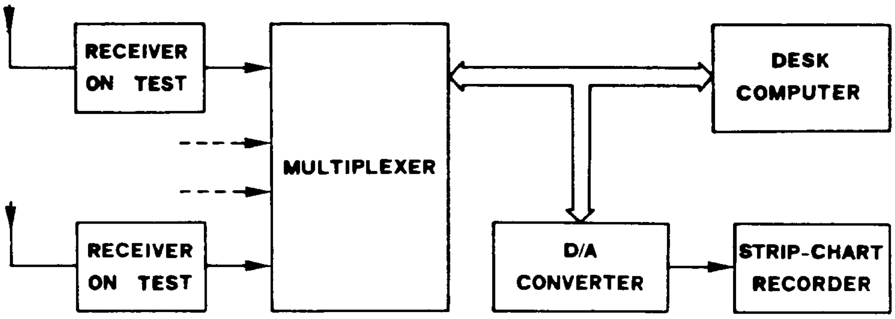

Fig. 2: Experimental set-up for cycle-slips phenomena detection

Each receiver was fed from its individual aerial, the antennas being mounted on the roof of the Electronic Department building, located in the middle of the town. At the beginning, the monitoring was performed on the four stations of the Mediterranean Sea chain. The Y-station (Targa-Barun, Turkey) was disregarded on the early phase of the experiment, since the cycle identification and some time also the signal acquisition, proved to be very marginal.

The signals coming from the other stations are adequate for an automatic tracking. The signal to noise ratios, as given by the receivers, usually follow the data of Table II, in which also the approximate path lenghts are given.

Table II

Station	M (Sellia)	X (Lampedusa)	Z (Estartit)
S/N ratio, dB	−6	−3	+7
distance, km	1016	1146	490
peak power, kW	165	325	165

With regard to the short term fluctuation in the time differences, the peak-to-peak values are typically 1 μs for the couple M – X and 1.2 μs for the couple M – Z. The one-sigma value is 0.1–0.2 μs, and consequently it is of the order of the time resolution of the receivers, that is at or around 0.1 μs. The value of the equivalent time constants used in the commercial receivers for the amplitude and phase servos are not known, but can be inferred to be in the order of 10–20 s, from the maximum allowed speeds for the host vehicle, that are between 100 an 160 km/h.

One of the available receivers, tested with an especially built Loran-C signal generator in which the phase of the signal can be moved with a fixed rate under computer control, shows a maximum tracking speed of 60 m/s, (about 220 km/h).

The peaks of fluctuations happen when the terminator crosses the path, consequently some contamination from the skywave should be present in the Torino area.

The most dangerous drawback for a navigation Loran-C receiver is the appearant cycleloss or slippage, since no clear warning can be derived, but the position can be grossly wrong.

An extended enquiry was consequently performed on this specific point, recording over 40 000 time difference measurements, one every ten seconds.

In no occasion, in daylight conditions a cycle error was observed both on the couples M – X and M – Z, during the night, error rates of 1.8 % and 30 % respectively for M – X and M – Z were found.

Phase measurements performed simultaneously on the individual carriers, with a time constant of 30 s, gave no evidence of troubles in propagation, consequently the encountered cycle slips were instrumental problems.

It must be stressed that the above mentioned statistics were derived with a receiver that proofed to be very prone to jump the tracking point in presence of ionospherically contaminated signals and to persist in tracking a non correct cycle. Other receivers have shown to be less sensitive to these phenomena.

4 Position "errors"

For land 'navigation' with Loran-C, in order to take into account the so called 'Additional secondary phase factor' (the amount, in time, by which the signals are additionally delayed by the various soil conductivities and profiles) – it is known that two approaches can be followed.

In the first approach, called 'conductivity mapping', a spatial distribution of conductivity is stored in the receiver and used to correct the readings.

The second approach called 'error mapping' is based on time difference readings performed on known points; a map of errors can be consequently formed and adjourned; obviously this second approach can be followed for limited areas and best when the data are to be treated in a central point where is located the computer with the 'error map'; these two features are encountered in the AMV systems.

For Italy, the orography being very complicated with soil conductivities spanning near two orders of magnitude and frequent sea-soil crossings for all the paths from the stations M, X, Z, the 'conductivity mapping approach' is cumbersome.

In some cases indeed, an agreement of few tenths of microseconds was found comparing the theoretical prediction with the portable clock result, but obviously this approach cannot be generalized.

Consequently the 'error mapping approach' was adopted as performed elsewhere [6].

In order to gather information, a van was instrumented, Fig. 3; the data received via the VHF link can be presented on a video display, with a kilometric or latitude-longitude graticule *(Fig. 4)* and can be stored for subsequent analysis.

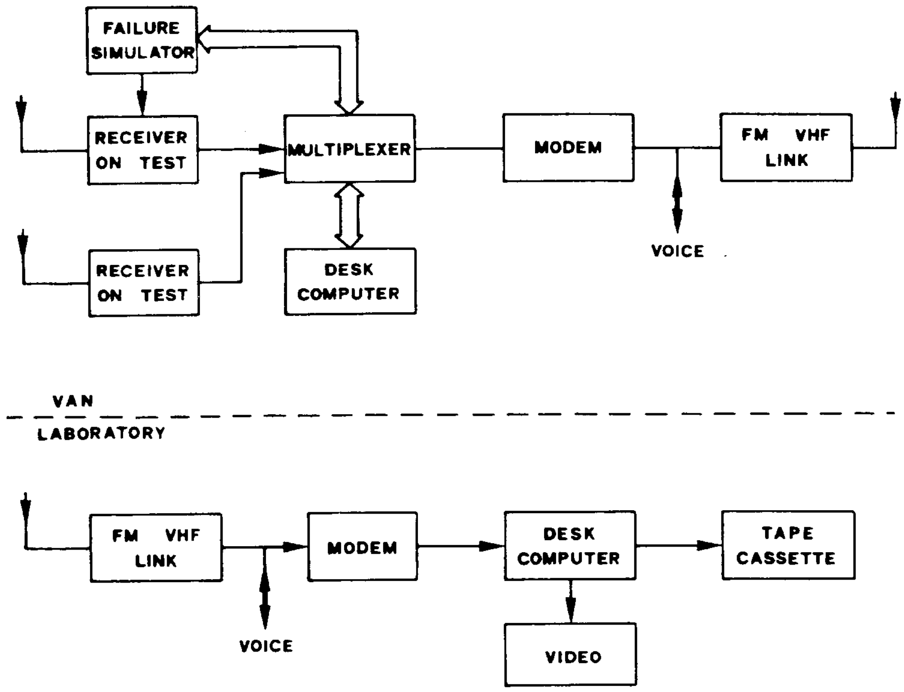

Fig. 3: Experimental set-up for error mapping

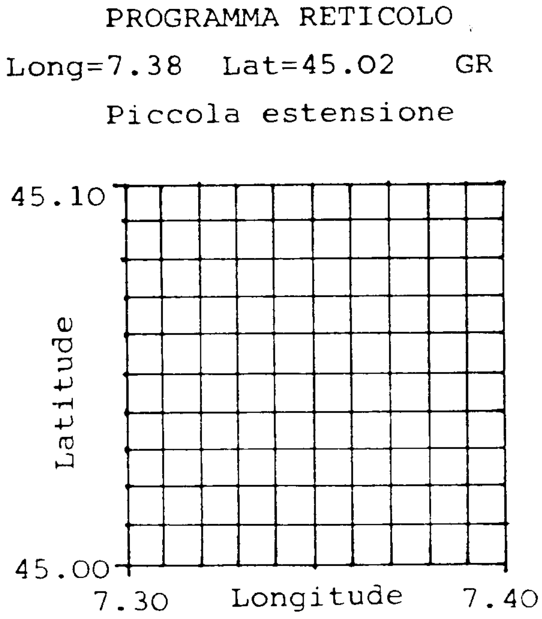

Fig. 4: Example of video displayed vehicle position

In the van a failure simulator, acting under control from the computer, can turn-off the individual receivers, in order to measure the time of requisition of the signal.

Some preliminary results are given in Fig. 5, in which, over a map of the town, are depicted the error vectors (measured position – real position), without any correction for soil conductivity, i. e., as the paths were fully over sea – water.

The average error is of 460 m with an azimuth of 40°; the onesigma standard deviation is around 125 m and no determination shows an error of more than 200 m, if the above mentioned average correction is removed from the individual measurements.

Downtown and in narrow streets between buildings more than 20 m high, errors or losses of acquisition can be encountered. On highways and wide boulevards at top speeds of 100 km/h, the tracking was successful, with a repeatability (not accuracy) in position of about 50–100 m.

5 Final remarks

From the first results, it seems possible the land 'navigation' with vehicles at the practicable road speeds, with errors in position between 100 and 200 meters, provided a propagation delay correction is implemented.

The position repeatability (not accuracy) can be better by a factor of two and combining the 'error mapping' technique with a sort of differential Loran-C, the repeatability can be improved to 30–50 meters. In an AMV system the differential Loran concept can be implemented easily, because the reference station can be installed in the same building where the AMV Data are gathered, in the AMV applications, obviously the differential data are not be disseminated to the individual users, as happens, for instance in the differential Omega system. In the proposed differential Loran-C, it is suggested to use as reference sources, the Loran-C timing receivers, for their better tracking capabilities and in order to introduce the relevant corrections for each path [7].

5.1 Choice of the receiver

An overview of the receiver design trends is given in reference [1], with the enclosed bibliography; here only some desired features pertaining to the AMV application are pointed out. First goal is a sensitivity of the order of 0.01 μV rms, with an automatic gain range of the order of 120 dB.

The receiver should have an adaptive band width and, if costs permit, the 'linear amplifier' detection instead of the hard limiting approach. The choise between the two techniques should keep in mind the fact that in Europe strong CW signals are present.

Some of these transmitters radiate above 50 kHz carriers that are frequency stabilized with primary atomic frequency standards, consequently a sort of highly coherent noise can hamper the detection. Similarly, sometimes, are present very strong Loran-C signals coming from the USSR.

The program of the receiver should be based on a permanent memory, this feature can afford the rejection of a specific station and the starting of each lock-on cycle with at least the first two-three figures of the final time difference values.

With regard to the hardware, the major problem insofar encountered are with the antenna, the grounding of the coupler and with not adequately protected power supplies; in some cases the receivers enter into a new acquisition cycle each time the van engine is started.

5.3 Future area of research

Being proved the long term phase stability, the 'error mapping' approach and the feasability of the 'differential Loran-C' concept, it remains to study in real cases,

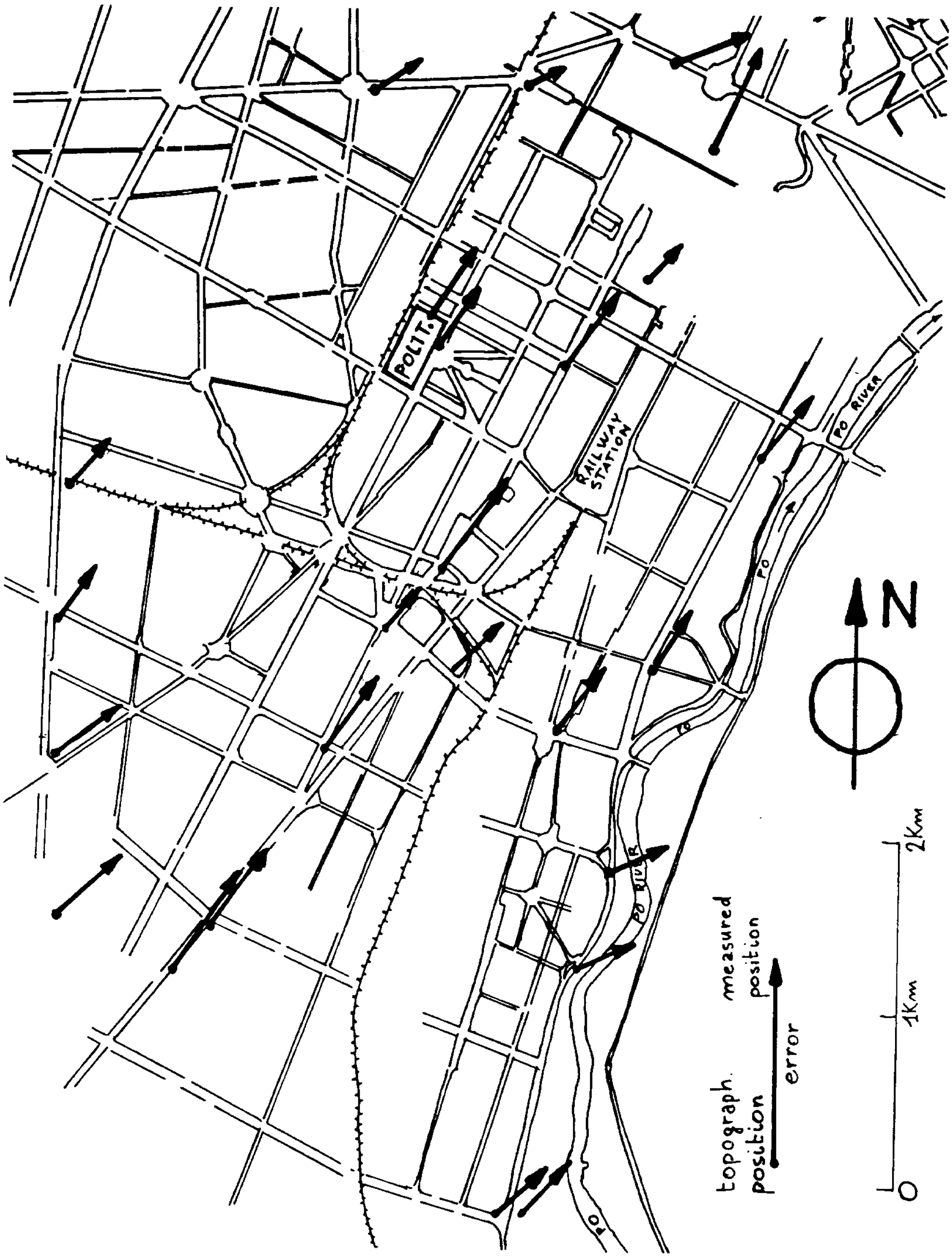

Fig. 5: Errors in Loran-C vehicle location

the extent of the area in which the above mentioned approaches can be adopted and what kind of simpler computing (such as the hyperbola tangents) can be followed for limited areas, if the profile of the soil is uniform. For instance, and with reference to Fig. 5, on the east side of the Po river, a very steepy hill region, the linear correction approach fails.

Finally, with regard to the hardware, some activity must be performed on the antennas, mainly as this device must remain unobtrusive or must be shared with other devices.

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