HEMISPHERICAL LUNEBERG ANTENNA MOTORIZÉD FOR SATELLITE RÉCEPTION FROM THE ROOF OF A VEHICLE

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Summary

The Luneberg lens owns the outstanding property to focus a wave coming from any direction very near to the opposite point of the sphere. Placing there a microwave feed (e.g. a small horn) builds an antenna able to receive (and conversely transmit) from/to the incoming wave direction. So mechanically moving the feed around the bottom half-sphere allows to scan the antenna beam over the whole upper half-space, if avoiding any shadowing from the lens support. Independent steering of the 2 feeds provides 2 beams, each pointing toward any required direction.

Practically, a Lüneberg lens comprises several hemispherical shells, built with cheap plastic material (polystyrene-type): the farther they are from the centre, the larger is their radius and the lower their density (i.e. the more expanded is their material.

From several years, Alcatel Space assesses various *Lüneberg antennas* as low-cost solutions for User terminals within Satellite communication systems, when one of the 2 linked antennas widely moves, requiring that the User antenna beam scan a large angular domain. In tight co-operation with Lun'tech, a SME located near Montpellier, and in the frame of a R&T study co-funded by CNES, this concept was successively applied to:

a) a fixed antenna tracking the satellites, part of a constellation in low orbit (as for the Skybridge project): a full 40cm spherical lens was assembled with 2 independent feeds, for fast switching from a satellite to another, after a short overlapping delay;

b) an antenna on a fastly moving vehicle, always pointing towards a fixed geostationary satellite: here the smaller range in elevation allows using a half-lens glued on a ground plane: the antenna height is much reduced, and well complies with the aero-dynamic constraints.

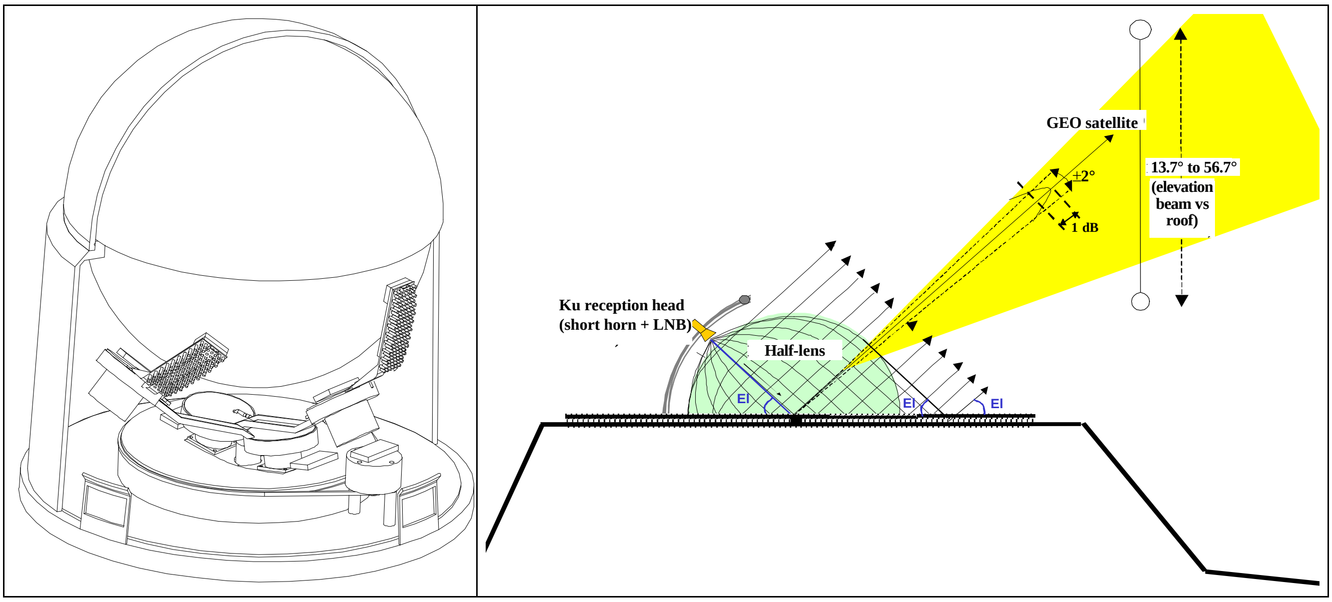


Figure 1 :a) spherical or b) hemispherical Lüneberg lens antenna for satellite communication system subscriber's terminals

Conception and manufacturing of Luneberg lenses

The lens is made of low losses dielectrical materials. The indices decrease from 2 to 1 all along the radius of the sphere, by sampling the theoretical law $n= 2-(r/R)^2$. Practically, the lens is made of several hemispherical layer fitted together, each layer has to be closed to a given permittivity, optimized with a electromagnetic simulation software (cf Figure 2).

The hemispherical antenna uses *the source image principle*, symmetric versus the reflector plane. This concept more compact is more suitable when wide angle sighting (alias elevation) are not necessary (masking by the feed), nor very small angle of sight (prohibitive extension of the overall plane).

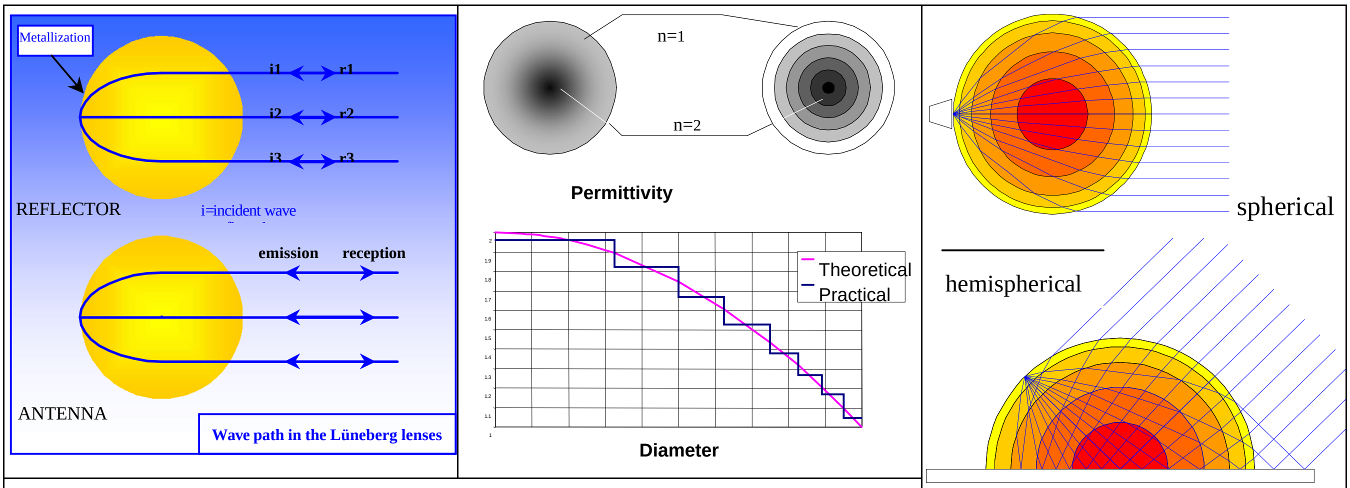


Figure 2 : Principles and variants of Lüneberg lenses

Up to now the Luneberg lenses are made for small production applications. The manufacturing is meant to remains made by « quasi traditional methods », with a process under control for 30 years by Lun'tech.

For this project, Lun'tech has been looking for new materials and new transformation technologies in order to lighten the lens, while permitting a low cost mass production with a good reproducibility.

Several materials have been tested. Only few have been kept: materials with polystyrene matrix. This matrix is more or less charged with a high permittivity constituent.

The results of all the transformation trials made were very promising, proving the technical feasibility with existing presses; the required densities have been obtained with adapted settings.

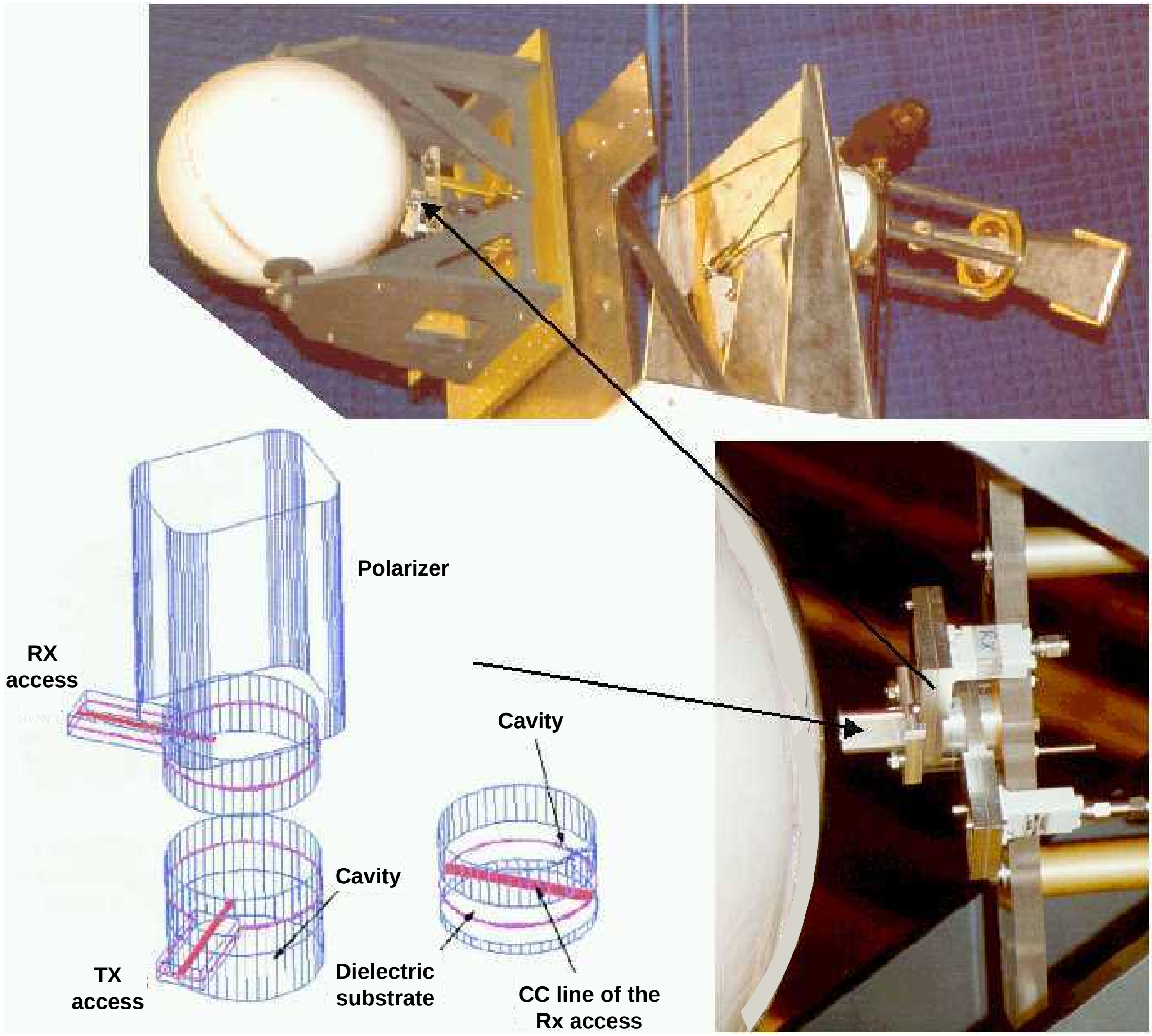
2 beams fixed antenna seeking 2 low orbit satellites

The wide band satellites constellations aimed to provide internet/multimedia access everywhere in the world *(ADSL in the sky)*, this required that every subscriber has a continuous liaison with a *gateway* via a satellite. When one of them went out of the visibility domain, the liaison was going from a satellite to another one.; during 1 second, the subscriber's antenna had to seek the 2 satellites simultaneously; to synchronize on the new satellite, 2 beams pointable independently were then required.

The concept studied and patented by Alcatel Space (cf Figure 1-a) used 2 Rx/Tx planar feeds, moved each at the end of a 2 axis articulated arm near the lower part of the Luneberg lens. A fifth motor rotating the plate supporting the basis of the 2 arms permits to unroll during the sequence the inevitable RF+DC connexion cables.

The active feed was emitting 1 to 2W-RF, and was including the SSPA in order to reduce all losses before radiation; the back side of the forearm's top has therefore been equipped with small thermal radiators. Finally, it was necessary to conceive a compact feed, receiving in the 11.8-12.6GHz band in right circular polarization, and emitting in the 14-14.3GHz left circular polarization (or vice versa) in *full-duplex*.

After several solutions had been simulated and modelled, the chosen concept (presented in Figure 3) succeed in realizing an insulation > 20 dB on both 2 bands: thus the screening before the LNA and after the SSPA can be reduced to 25 DB and realized in a small volume on each forearm. A prototype without amplifier has been measured; in association with the 40 cm Lun'tech lens, the patterns were below the strict side lobes target pattern fixed by UIT-R in order to avoid to pollute other Ku band telecommunication systems.



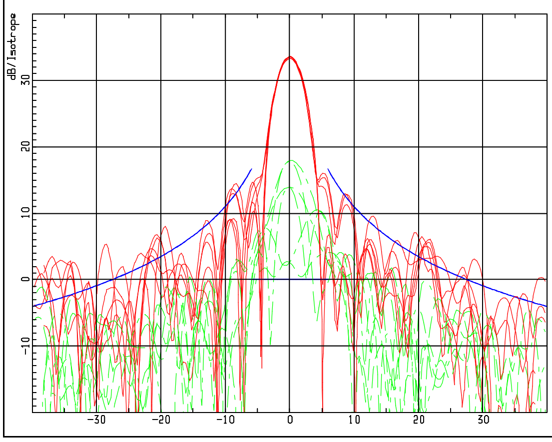
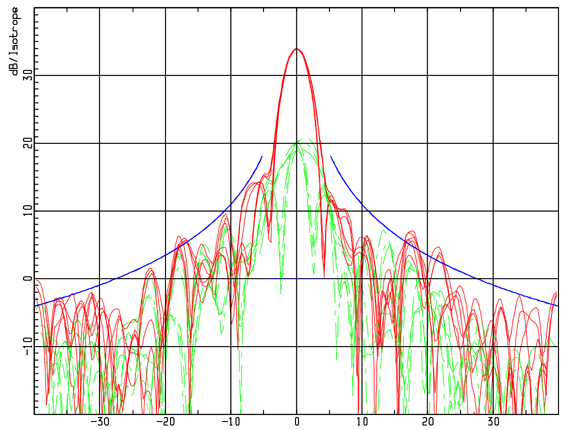


Figure 4 : Patterns of the spherical lens antenna ∅ 40cm: 2 sections ⊥ at 3 freq in the bands:

Ku-Rx ←

and Ku-Tx →



Mission of the « Ku band DMB reception » antenna on vehicle

Afterwards, the previous mission has been suspended (the multimedia-constellations projects have been put on ice) to the benefit of a the « Ku mobile » antenna that have to be integrated on the roof of a vehicle (cf Figure 1-b):

- First of all on buses, camping-cars, fireman's cars…, then more generally on top of the range cars;

- That will allow to receive a set of services called Digital Multimedia Broadcasting (DMB): receive general data from a region (meteorological, tourism, traffic information, etc…) or specific on user's request via terrestrial phone networks; high quality digital radio even in badly-served by FM emitters areas; pre-recorded movies loaded in cash-memory and then displayed for rear passengers, etc…
- All this from one of all the Ku transponder available in satellites toward the end of their lives (the position can move away of a few degrees from the theoretical geostationary orbit, but the drift is well known and supplied by the system operator. This small drift has only a small influence on the wide scanning domain necessary for the antenna beam.

The specifications applied to this antenna are developed at the end, compared with the performances measured on the prototype.

Main constituents of the Vehicle Terminal antenna (Rx-DMB/Ku)

The figure # 1-b presented the prototype conceived, manufactured and tested; to make the tests easier, the commercial LNB was replaced by un small passive horn. In order to intercept the main part of the hemisphere's radiation (made of 6 layers, for a diameter 2R = 23cm), even for the low sighting, the overall plan must have a diameter ∅=2R/sin(Smin) = 90cm. It has been deduced from the prototype that the height of an operational antenna would be around 25cm.

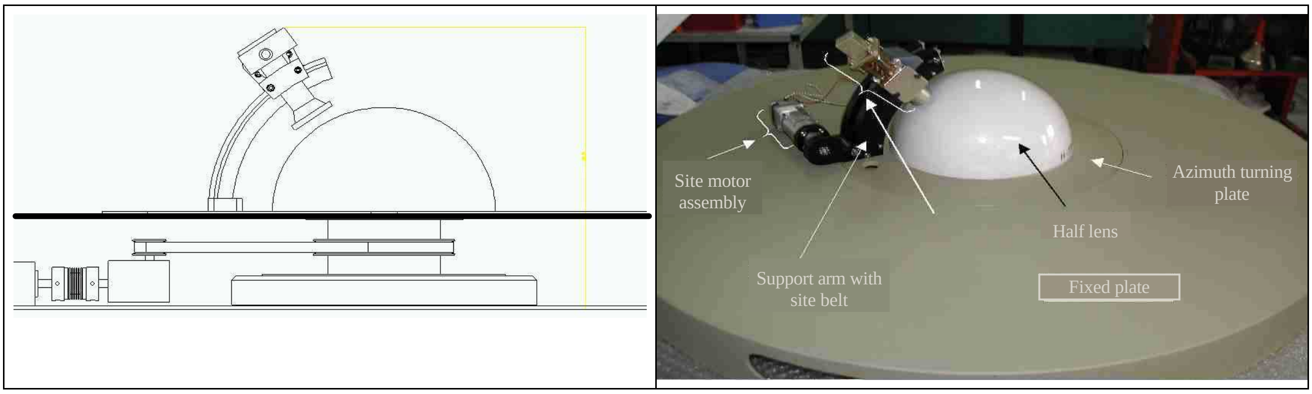


Figure 3 : Simplified section of an operational antenna (a), prototype (b)

Pattern and gain of a spherical or hemispherical lens antenna of 23 cm

First of all, a spherical lens with a diameter 231mm, focalising at 5mm from the surface, has been developed by Lun'tech and measured in their anechoic room at 12m, illuminated by a wave guide feed type WR75 slightly opened. Then an hemisphere (less than 1,5kg with standard materials and processes) was integrated in the Ku-mobile antenna prototype.

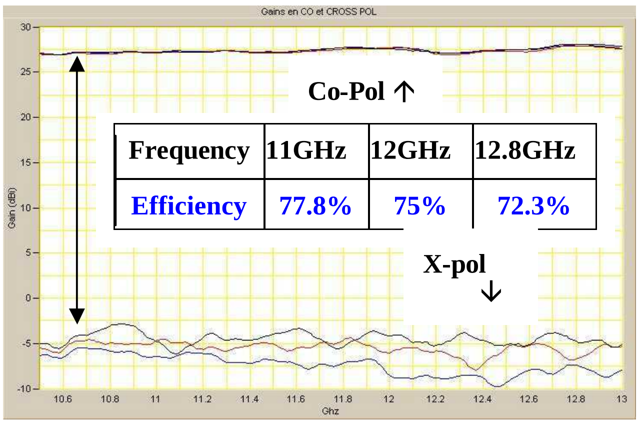


Figure 4: Gain in Co and Cross-Pol

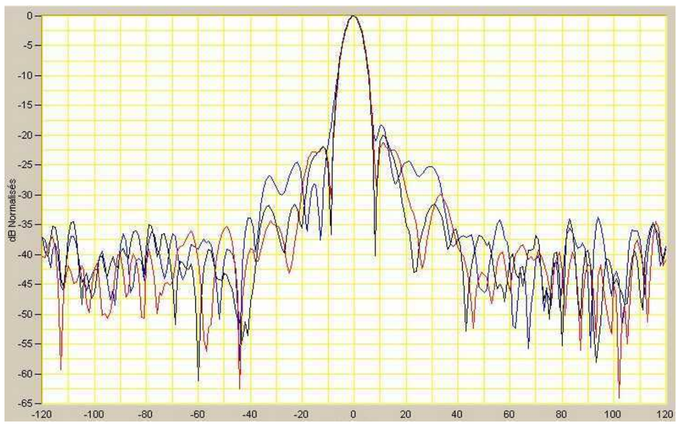


Figure 5: Patterns in Copol (sections 0°,45°,90°)

The patterns of the hemispherical lens antenna (glued on the overall plan) are quite similar:

- The side lobes are very close to the target pattern negotiated with UIT-R for the Skybridge project; The self-pollution by the signals from the close satellites slightly contribute to the global SINR (Signal to Interference and Noise Ratio).
- The gain decreased of around 1dB because of the limited dimensions of the overall plan for low angles of sight and because of the masking by the feed support arm for high angles of sight. But a margin > 1dB is maintained for the main specification in G/T (see Final Table).

Servoing from a « Differential GPS » for the mechanical pointing and errors report

The pointing is in *open loop*: the controls of the 2 motors (Sight S ; Azimuth A) are updated on real time with a small computer processing satellite's and vehicle's positions, and above all the fast altitude variations of the vehicle, function of bend **b**, its pitching **p** (slope of the road up to 10% + defects of the suspension) and its rolling **r** (up to 3° in the curves).

For an operational antenna, 2 types of attitude sensors are competiting (or completing but with a high cost):

a) clinometers and electronic compasses for static values (**b,p,r**); and miniature gyros for dynamic variations.

b) the same information can be obtained from a *differential GPS* using 4 identical patch antennas placed on the corners of the vehicle, and a single fast switching receiver [most of the errors of a couple "receiver + single antenna" are removed by processing the phase difference between the signals received on the 4 antennas, from each satellite]

The (b) solution was considered the cheapest at long term, thanks to corresponding market, and enough precise with GPS signals downgrading, the next competition with GALILEO, and the complementarity of the GLONASS constellation. In any case, a single antenna receiver would have been necessary in order to know precisely the geographical position of the vehicle. From a revue of the commercial products and of articles concerning measurements in real conditions on a vehicle, the precision of the 4 points position difference measurement was estimated to ± 1.2°cm (at 2.5σ) in differential mode.

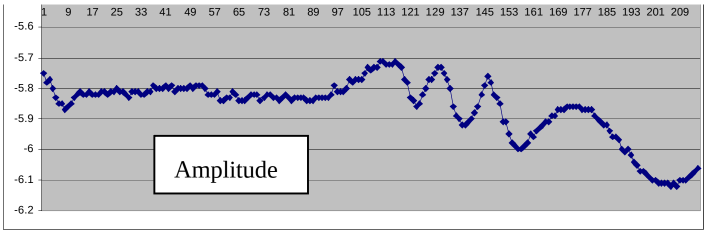
An exhaustive analysis of the error sources was carried out: sensors, command delays, mobile parts play…To reduce their impact, a sequence of initial setting by multiple sighting of a reference satellite on the installation site has been proposed, at 4 bend values spaced of around 90°;;the electronic stops are set. They are used as reference point by the antenna mechanics at the beginning of each course, or in case of switch-over. Then, the H or V polarization will be aligned on the polarization of the satellite at the beginning of each course by turning by hand the feed-LNB assembly on a vernier, from an angular target supplied by the computer. All the errors summed in RSS, 0.5dB in gain are lost (pointing precision ± 1.2°), and the cross polarization is -15 dB.

Simulation of satellite-pursuit in antennas test anechoic chamber

A software has been developed, to control in rated the antenna motors for an actual trajectory of the vehicle, but also simultaneously les 3 rotation axis of a positioner of antennas basis, simulating the movements occurring on a typical road joining Alcatel Space to CNES via the nearby vineyard. The algorithm summarized below has been installed, including many matrix transformations between 5 sets of different angular coordinates ["absolute" / local / linked to the vehicle / to the antenna / to the positioner geometry reference point], and interfaced with the drivers of the concerned motors:

longitude, latitude, altitude (Sat. & véhicule) →	[**Az,El**] Sat. vu véhicule pointé Nord • attitude véhicule sur route (l,t,r) →	[**G,S**] commandes moteurs antenne [Y ,X ,Z] commandes positionneur

The statement of the received signal amplitude and phase variations, with periodic samples of the trajectory (215 below), shows a continuous variation of the phase (avoiding any risk of *switch-over* of the receiver) and a dynamic in amplitude of 0.4 dB peak to peak. Another part of the road, measured in H and V polarization, shows similar results, confirming the algorithm accuracy, and the antenna capacity to pursuit the satellite despite large movements of the vehicle in (**b,p,r**), reaching the extreme specifications in term of slope (≈10%) and rolling (3°):



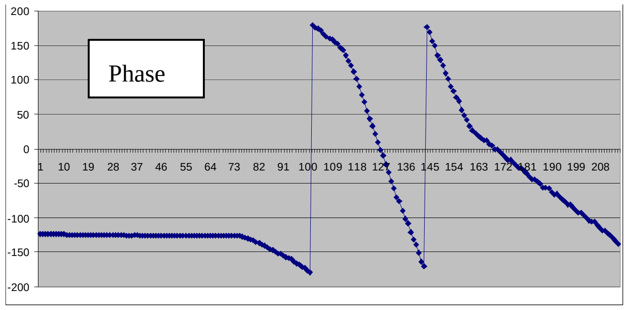


Figure 5 Received signal Amplitude / Phase during the simulation of the satellite pursuit, sampled on 215 points

Synthesis : the performances of the vehicle antenna are conform to the specifications

Criteria	Band/polar	Movements	Mecha/pointing	Patterns	Gain	**G/T**	SINR with Xpol
Initial specifications	11.2-11.7 GHz / H or V	Circulation on all Europe Slope < 10% rolling < 3°	Any G on 3 tours 13.7°<S<56.7°. dG/dt<45°/s, dS/dt<6°/s. <u>ε pointing< 2°</u>	* 1er lobe < -16dB/max * far lobes <-6dBi	> 24.9 dBi max	**> -1 dB/K** : [T ≈ 270 K ; losses of gain ΔG = 1.6 dB]	3 dB (high errors corrector coding + temporal repetition vs masking)
Measurements /simulations	OK / <u>XPD > 15dB without motor of polar (30 dB for antenna alone)</u>	Sat elevation GEO=22.4°at 48°/ Vehicle movem^{ts}→ δS<7.5° / δ(lat)Sat ±1.2°	OK from Aberdeen / Stockholm to Malta / South of Greece. Motor speed OK. <u>ε pointing<1.2°</u>	* <u>1er lobe < -17dB/max</u> * far lobe<u>s</u> <u><-6dBi</u>	25.2 à 25.7 pr 3 freq x 2 pol x 3 sites	ΔG = 0.5 dB + 0.3 dB estimated for radome → **G/T> 0.1 dB/K**	OK with Xpol= -15 dB and SINR (out of X-pol) = 3.3 dB

Conclusion

The concept « Lüneberg lens antenna », <u>single</u> focalising device allowing a very large angular screening at low cost, has been applied successfully en Ku band to a fixed antenna (2 Rx/Tx beams in circular polarization), communicating with polar-orbiting satellites, <u>and</u> with an antenna on a vehicle (Rx mono beam in linear polarization) with fast movements, which has to remain pointed on a geostationary satellite. In both case, the antenna shows a global efficiency close to a parabola, with the huge advantage to point any direction only mechanically moving light parts, allowing a higher compactness, and guaranteeing a good pointing accuracy with a low wind factor under a profiled radome.