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Tallysman Wireless Inc
NAVISP-EL2-023 “Super Antenna”
ESA Contract 4000124064/18/NL/MP/mk
Final Report

NAVISP2 – Final Report - TALLY - 01 - 03

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Approved - Tallysman	Approved – ESA Technical Officer
Neil Knudsen - Project Manager	

Executive Summary

We have developed a commercially viable GNSS antenna with superior electrical properties. The VeroStar^{TM} antenna has an industry leading sensitivity at low elevation angles, high efficiency, very low axial ratio, and high phase center stability. This light weight and compact antenna element is packaged in several robust housings designed and built for durability and will stand the test of time, even in the harshest of environments.

The VeroStar^{TM} antenna has sufficient bandwidth to receive all existing and currently planned GNSS signals, while providing high performance standards. Testing of the antenna has shown that the new novel design (curved petals coupled to crossed driven dipoles associated with a high performance LNA) has excellent performance, especially with respect to axial ratios, cross polarization discrimination and phase-center variation. These features make the VeroStar^{TM} an ideal rover antenna where low elevation angle tracking is required, bring new levels of positional accuracy, and benefits to users.

The project is now complete and while the end result is different from that originally proposed the project has been proven quite successful. Among the positive highlights:

- The tests indicate an antenna whose performance is among the best in the world, but with costs in line with medium priced competition.
- The design is simple and robust, and production is straight forward, with no complex elements. The adjust on production component of the design has been eliminated.
- The size of the element is small (8.5 cm D x 3.4 cm H = 193 cm^3), and the mini (7.2 cm D x 2.4 cm H = 98 cm^3) extends that advantage by a further 50% at a cost of approximately 1 dB of performance.
- The wide bandwidth and high performance at low elevations means the antenna is well suited to also receive L-Band signals from Geostationary satellites, allowing systems to also incorporate GPS correction signals (and so provide even higher accuracy) with a single antenna.
- 250 units have been sold to date, mostly for prototype and field trials.
- The company is in advanced discussions with a major agriculture equipment supplier whose forecast is for between 10,000 and 50,000 units annually (50,000 Is their total usage. The number that could be filled by the Tallysman super element depends on final costs and other commercial considerations).
- The mini-super element has been designed into an array by a European antenna manufacturer.
- The company continues its relationship with a European receiver manufacturer who is planning to incorporate the element into a new “smart antenna”.

2 - Project Objectives

The original Tallysman contract (ESA Contract 4000124064/18/NL/MP/mk) had the objective to design and develop a single “super element” that could be configured in production to have its performance optimized for either low or high elevation operation. This would translate, roughly, to optimization for either the aviation sector or the marine/agriculture sector. A housing would be designed specifically for each application area, and each would be fully tested and certified.

The central goal of this project was a precision antenna element with a broad beamwidth, a good AR combined and a very tight phase centre variation. The objective was to provide for reception of signals from satellites at low elevation angles, particularly necessary for reception of L-band correction signals which can be expected to be incident at elevation angles of 10 degrees to 50 degrees above the horizon.

Centre frequency(ies)	L1, L2, L5, E1, E5ab, E6, G1, G2, G3, B1, B2, B3 +1525 – 1559 MHz
Gain @ Zenith	L1: 4.5 dBic L2: 4 dBic L5: 3.5 dBic E5: 3.5 dBic E1: 4.5 dBic G1: 4.5 dBic G2: 3.5 dBic
LNA Gain	33-35 dB
Noise Figure	< 2 dB
VSWR	<1.5:1 max
L1 – L2 Differential Propagation Delay	< 5 ns
Group Delay Ripple	< 5 ns
Axial Ratio	< 1 dB at zenith, 3dB max at horizon
PCV	±1mm
Power	< 55 mA
Voltage	+2.7 to 24VDC
Connector	TNC
Water	IP69
Weight	450g
Size	14 cm x 6 cm
Mounting	5/8” x 11 tpi
Price (USD)	300-750

As the original project progressed, several factors became clear:

- It was possible to design a single super element that did not need configuration in production, yet still met the design objectives of both original configurations. This was a major design accomplishment that was achieved early in the project, and which drove some of the following alterations.
- The certification of the aviation housing would be much more expensive and time consuming than originally projected.
- There is a standard aviation housing (ARINC) which could be used if the super element could be shrunk down in size slightly. This would allow initial access to the aviation market without the long and costly certification of a purpose-built housing.
- There has shown to be a strong market for a small, OEM antenna element sold without a housing. This element would find uses in smart antennas, arrays and the above mentioned ARINC application.

As such, a CCN was executed that made the following changes to the project objectives:

- To design a single “super element” antenna (still meeting all the original technical criteria).
- Follow on with the design of a “mini-super” antenna, with only slightly reduced performance, but a size (approx. 50% reduction in volume) that meets a large and unmet OEM market.
- Produce a marine/survey housing (post mounted) and have it tested and environmentally certified.
- Design a second agriculture housing (flat mounted) but do not complete the full certification until the market has developed and the design elements incorporated in the marine/housing have been confirmed in the field.

3 - Key Issues

As the project progressed, there were several issues raised:

Antenna configuration

The initial testing showed that the original performance specifications were achievable with one exception: we were unlikely to be able to produce a single design that could be adapted at production for specific markets. The mechanical design needed to meet the "adapt on production" goal was fundamentally incompatible with the design required to meet our performance goals. As is often the case in engineering projects, we decided to forego the adaptability goal in order to keep the performance goals intact. Subsequent work revealed that in fact a single unit could be designed that would meet all the original specifications of the project.

Software

The original proposal envisaged that Tallysman would develop software tools to assess the semi-infinite interactions between commonly expected high level signals arising from amplifier non-linearities (eg, cell phones and cell towers of many frequencies, Iridium and Inmarsat transmissions, etc). In fact, we allocated significantly more effort to development of the element than anticipated and we limited our evaluation of harmonic products and intermodulation to signals that we are presently aware of both in Europe and across North America. The antenna structures were simulated using WIPL-D, a commercial EM software package.

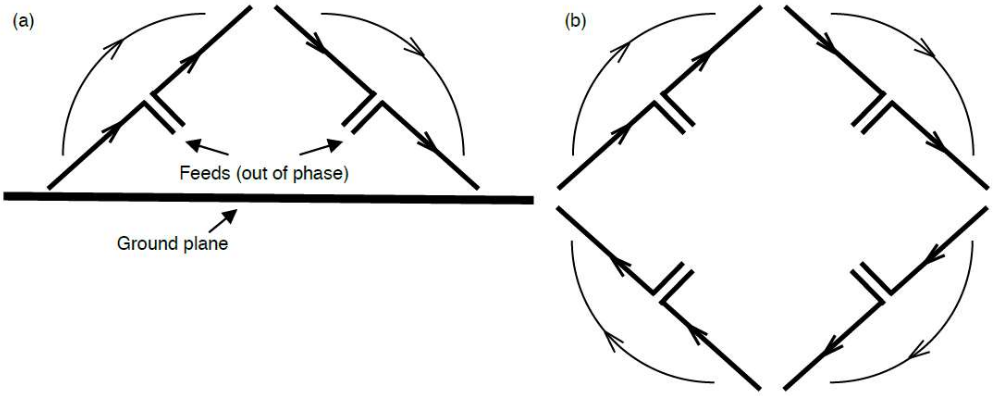
Additionally, Tallysman developed MATLAB code to estimate the PCV from the measured radiation pattern.

Data files from these applications are included with the project data package.

4a – VeroStar™ Standard– Design Notes and Performance Results

Introduction

A starting point for this development was an in-depth study of the well-known Dorne & Margoline (DM) C146 antenna. This antenna has been used for decades in GPS reference stations (usually in choke ring antennas). It exhibits a higher gain at low elevation angles (about -3 dBic at horizon) compared to other antennas on the market (typically –5 dBic or less), and a fairly good phase-center stability in a compact design. The antenna structure consists of two orthogonal pairs of short dipoles above a ground plane, with the feeds at the midpoint of the dipoles, as shown in the following figure (a). The antenna can be considered in terms of the ground plane image, replacing the ground plane with the images of the dipole as shown in the figure (b). The antenna structure then takes on the form of a large uniform current circular loop similar to the Alford Loop antenna.



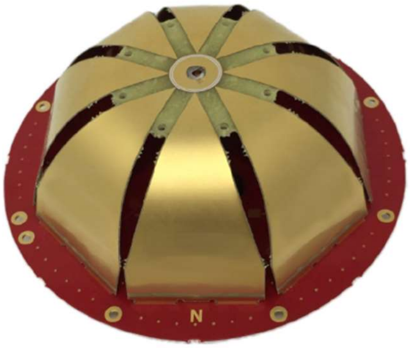
The DM antenna also suffers from some drawbacks. By modern standards, the feed network is complex and lossy and costly to fabricate, which affects repeatability and reliability. The AR at zenith is marginal (up to 1.5 dB) and further degrades to 7 dB at the horizon, a factor that become less relevant in a choke ring configuration where the DM is the most commonly used. However, we took our inspiration from the DM structure and give a nod to its original developers.

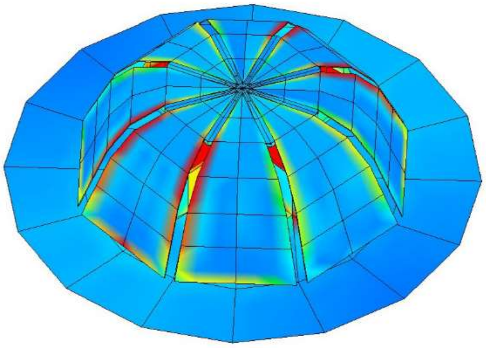
The key innovation elements in the VeroStar are the radiation petals, the feed network (including the LNA) and certain associated construction techniques, all of which have been protected by a patent application..

Antenna Structure

The structure of the VeroStar™ antenna is shown below.

The element consists of bowtie radiators (petals) over a circular ground plane. The petals are coupled to a distributed feed network comprised of a simple low loss crossed dipole located between the petals and the ground plane. The relationship between the petals and the associated feed system provides a current maximum at the curvature of the petals instead of at the center of the antenna as seen on the following figure, and in this respect achieves a current distribution similar to the DM element. This increases the gain at low elevation angles which greatly improves the link margin for low elevation GNSS and L-band satellites. The circular polarization of the antenna at low elevation angles can be significantly improved by optimizing the petal's characteristics such as its height, width, and its angle with respect to the ground plane. This solves the problem of asymmetry between the E and H planes of the antenna radiation pattern, which usually degrades the AR at low elevation angles. Based on the studies conducted in this project, it was found that the bowtie geometry of the radiators, as well as their coupling to the feeding network, can improve both the impedance and AR bandwidth. The result is a very wideband, low loss antenna covering the entire GNSS frequency range from 1150 MHz to 1610 MHz. The matching losses associated to the feeding network are under 0.3 dB and the axial ratio remains around 0.5 dB at zenith and typically under 3 dB at horizon over the whole GNSS frequency range.





In the early stages of the project four petals were used. However as we progressed with further experimentation and simulation it became clear that increasing the number of petals gave substantial improvements in symmetry, but at the cost of complexity. Ultimately 8 petals were chosen to provide considerably better symmetry than 4 petals with a "do-able" compromise on feed complexity.

Mechanical precision and reproducibility

Efforts related to the mechanical design of the element focused on reducing the overall cost, the feed network loss and ensuring production reproducibility. A series of RF simulations were conducted, and bench prototypes were built and evaluated. Early on it was decided to replace the original plastic support domes and the very thin PCB layer with a single 0.2 mm thick FR4 substrate layer with a printed copper layer on it. A 1mm thick stiffener was added to ensure the flatness and rigidity of the structure at the top of the antenna element.

In the design, the original impedance transmission feeding lines and associated small capacitors were replaced by two printed crossed dipoles printed on two low loss Rogers board substrates located under the FR4 layer. The dipoles are fed by their own internal printed balun transformer. Each top copper layer access printed on the FR4 board is coupled with the corresponding dipole fed by an internal printed infinite balun transformer which replaces the previous four-feed network. The infinite balun is also fed with a low loss internal transmission line. This way only one 90-degree hybrid transformer is necessary to feed the whole antenna element.

That new design ensures an extremely low loss feed network but also precision and reproducibility because the feed network and the coupling mechanism are defined by the board fabrication tolerances which are very tight. The low loss will be illustrated below with the efficiency measurement results.

Design Considerations

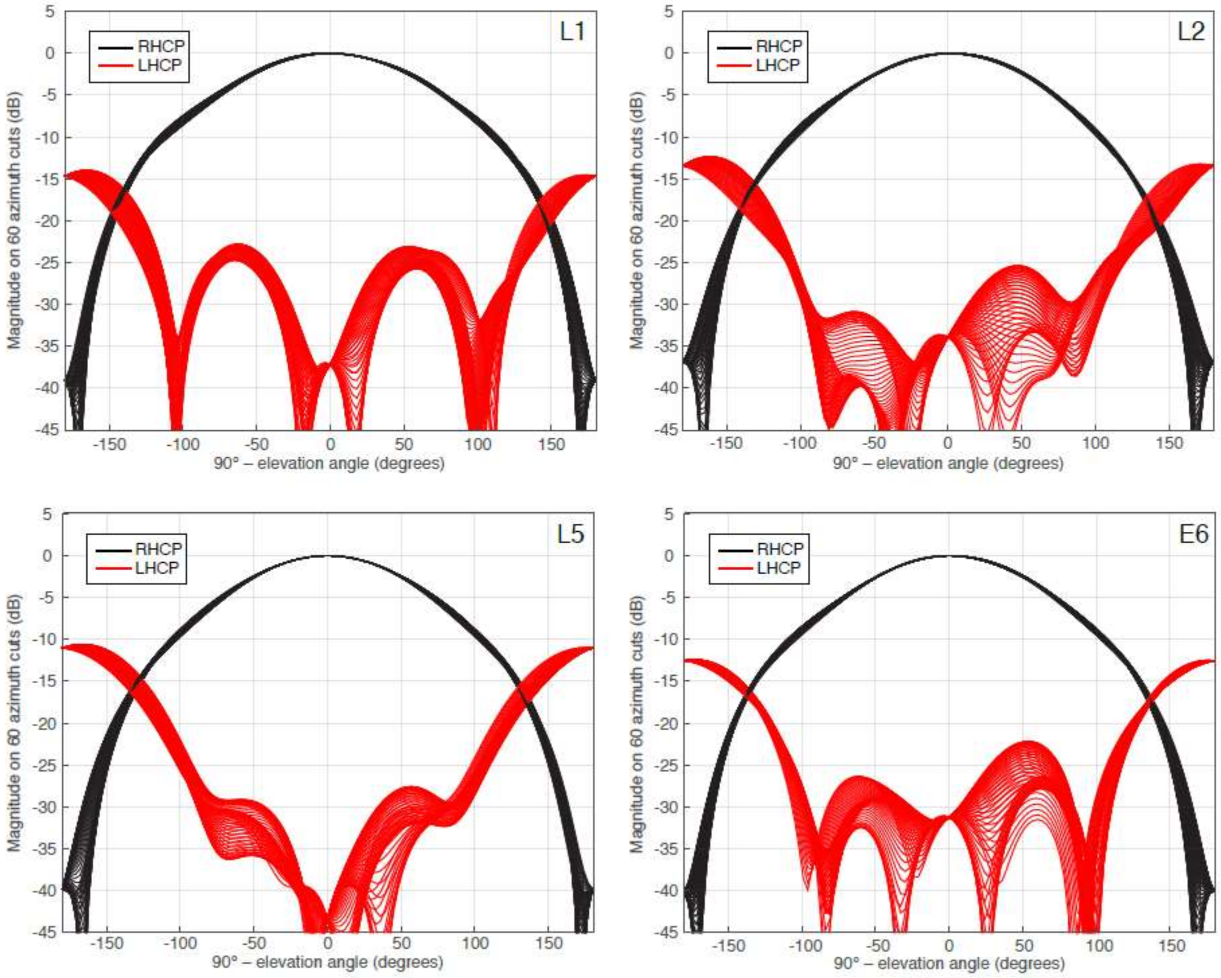
As the work on the antenna progressed, the original design criteria were always kept in the fore. Below we have highlighted the key design considerations and the performance results stemming from the final design.

Far-field characteristics of the VeroStar^{TM} antennas were measured using the Satimo Anechoic chamber facilities of MVG in Georgia and at Syntronic, Canada. Data were collected from 1160 MHz to 1610 MHz to cover all the GNSS frequencies.

i) Radiation Patterns, Low Elevation Tracking and Gain Roll Off

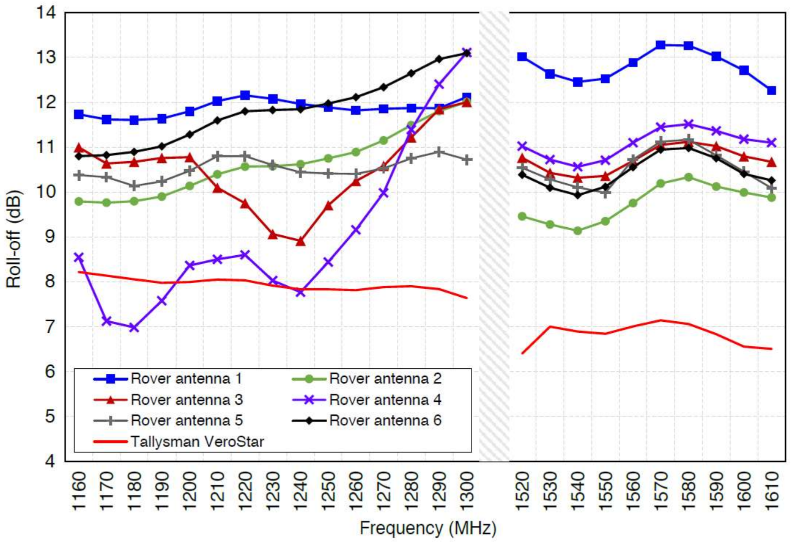
The measured radiation patterns at different GPS frequencies are shown in the following figure. The radiation patterns are normalized, showing the RHCP and LHCP gains on sixty azimuth cuts three degrees apart. It can be seen that the LHCP signals are significantly suppressed in the upper hemisphere at all GNSS frequencies. The difference between the RHCP gain and the LHCP gain ranges from 31 dB to 43 dB, which ensures an excellent discrimination between the signals. Furthermore, for other upper hemisphere elevation angles, the LHCP signals stay 22 dB below the maximum RHCP gain and up to 28 dB from 1200 MHz to 1580 MHz.

The figure also shows that the antenna has a constant amplitude response to signals coming at a specific elevation angle regardless of the azimuth angle. This feature yields an excellent phase center variation which will be discussed below.



Most commercially available GNSS rover antennas have a peak gain at zenith of about 3.5 dBic to 5 dBic with a roll-off at the horizon of 10-12 dB. Typically, this provides an antenna gain at horizon, at best, of about –5 dBic, which is insufficient for optimized L band correction usage. In the VeroStar^{TM} design we used wide bandwidth radiating elements (referred to as "petals") that surround a distributed feed network. The petal design is important to achieving superior Right Hand Circular Polarized (RHCP) gain at low elevation angles.

The figure below shows a comparison of the VeroStar^{TM} roll-off with six other commercially available rover antennas measured during the same Satimo session. It can be seen that the VeroStar^{TM} roll-off is significantly lower than the other rover antennas. The amplitude roll-off from the VeroStar^{TM} boresight (zenith) to horizon is between 6.5-8 dB for all the frequency bands.



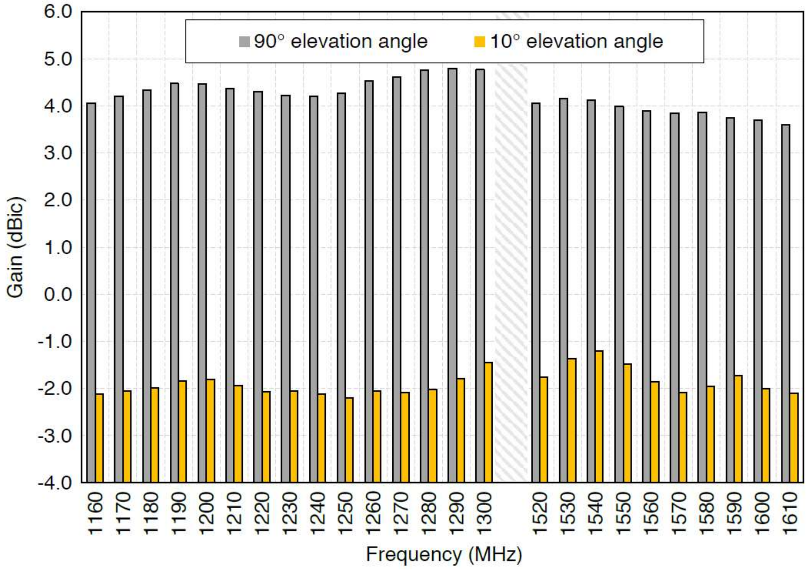
It is known that high gain at low elevation angles (low roll-off) will cause the antenna to be more susceptible to multipath interference. However, in conventional antennas, low elevation angle multipath degrades observations due to the poor AR performance and low up-down ratio. At lower elevation angles, the VeroStar™ has exceptional AR performance and a good up-down ratio, which significantly reduces multipath interference. Measurements in a high multipath environment were performed with the VeroStar™ antenna and compared to other commercial rover antennas. The VeroStar™ measurements show that the phase noise at 5 degrees elevation angle is approximately 6 mm to 10 mm over all GNSS frequencies. The other antennas performed similarly but had a higher roll-off (i.e.: lower gain at horizon). This shows that the VeroStar™ provides a strong signal at low elevation angles and has industry leading multipath mitigation performance.

ii) Antenna Gain, Efficiency, And Impedance

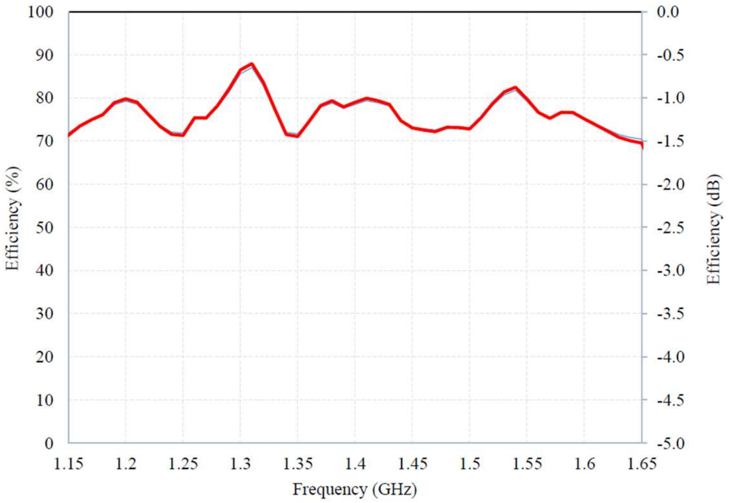
The VeroStar™ petals are parasitic resonators that are tightly coupled to a distributed feed network which is itself intrinsically narrowband. The resulting wide bandwidth response results from the load on the feed network provided by the excellent wideband radiation resistance of the petals.

This arrangement was chosen because the resulting impedance at the de-embedded antenna feed terminals is close to the ideal impedance required (50 Ohms), thus requiring minimal impedance matching. The near ideal match over a wide bandwidth is very important because it allows the impedance to be transformed to ideal using a very short transmission line (less than lambda/4), that includes an embedded infinite balun.

The following figure shows the RHCP gain of the VeroStar™ at zenith and 10-degree elevation angle for all GNSS frequencies. The measurements show that the antenna exhibits a gain range at zenith from 4.1 dBic at 1160 MHz to 3.6 dBic at 1610 MHz. It can be seen that the antenna gain at 10-degree elevation angle varies from –1.45 dBic to –2.2 dBic and is maximum in the frequency range used to broadcast L-band corrections (1539 MHz to 1559MHz).

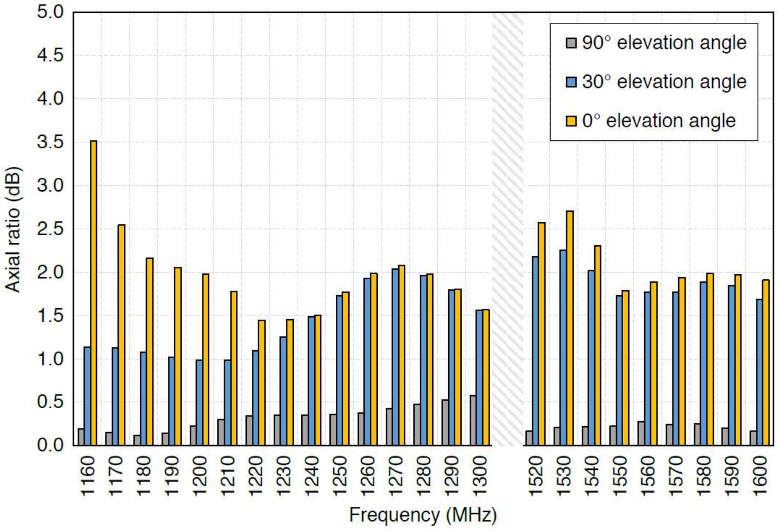


The radiation efficiency of the VeroStar™ both in percentage and loss in dB is shown below. It is observed that radiation efficiency is between 70 percent to 89 percent over the full bandwidth. This corresponds to an inherent ("hidden") loss of only 0.6 dB to 1.5 dB, including copper loss, feedline, matching circuit and 90-degree hybrid coupler losses. This performance is a substantial improvement over other antenna elements such as spiral antennas which exhibit an inherent efficiency loss of close to 4 dB in the lower GNSS frequencies. With the integration of a wideband prefiltered low-noise amplifier (LNA), a G/T of –25 dB/K at 10 degrees of elevation was measured.

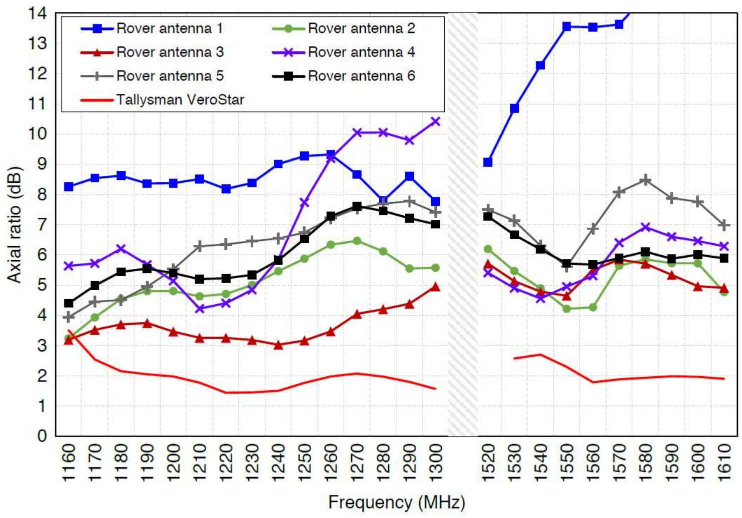


iii) Axial Ratio and Up-Down Ratio

Since the VeroStar™ antenna has more gain at low elevation angles, a very low AR and a high up-down ratio are even more important to mitigate multipath interference. The design objective was an AR of 3dB or better at the horizon. The AR values of the VeroStar™ antenna at different elevation angles are shown below. As can be seen, the VeroStar^{TM} has exceptional AR performance over all the GNSS frequency bands and at all elevation angles with the value no more than 3.5 dB. This increases the antenna's ability to reject the LHCP signals that are caused by the reflections from nearby objects such as cars or buildings. Therefore, the susceptibility of the antenna to multipath interference is greatly reduced.



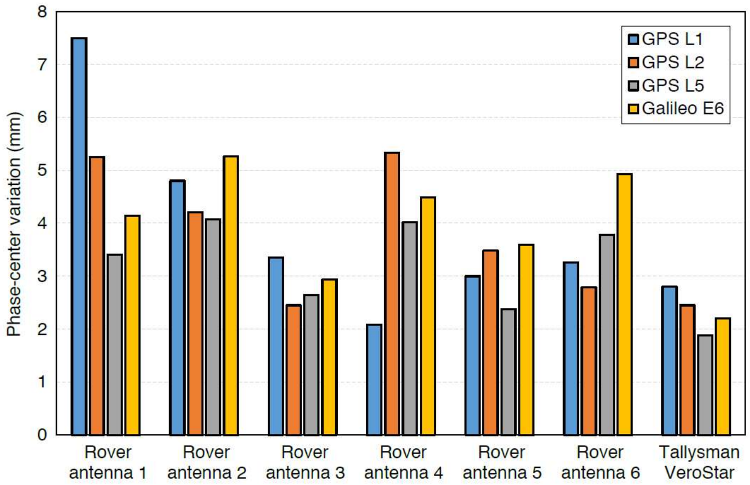
The AR performance of the antenna at horizon was compared to six commercial rover antennas. The VeroStar^{TM} antenna, with an average AR of 2 dB at the horizon, has the lowest AR among these antennas (competitive antennas are typically around 6 dB), showing its ability to track pure RHCP signals and enabling outstanding low elevation multipath mitigation.



iv) Tight Phase Center Variation

The VeroStar^{TM} is ideally suited to RKT or PPP applications. In this case the accuracy of the combined system is largely determined by the PCV of the smaller rover GNSS antenna. Thus, even with corrections data, azimuthal symmetry in the antenna is key. In the VeroStar^{TM}, this was addressed by obsessive focus on symmetry for both the antenna element structure and mechanical housing design.

Tallysman developed MATLAB code to estimate the PCV from the measured radiation pattern. We evaluated the maximum PCV of the VeroStar^{TM} antenna and six commercial rover antennas for four common GNSS frequencies. It can be seen in the following figure that the antenna has a maximum total PCV of less than 2.9 mm for all frequency bands which is less than the other commercially available rover antennas. Furthermore, the PCV of the VeroStar^{TM} antenna does not vary significantly with frequency. This comparison confirms the exceptional low PCV of the VeroStar^{TM} antenna.



v) Low Noise Amplifier (LNA)

One of the main components of a GNSS antenna is the low noise amplifier (LNA) which is used to amplify the GNSS signals and attenuate the out-of-band interference signals. Components like the front-end filters and the transistors are critical to keep a very low noise figure (2 dB or better) and avoid saturation in the presence of an in-band interference signal.

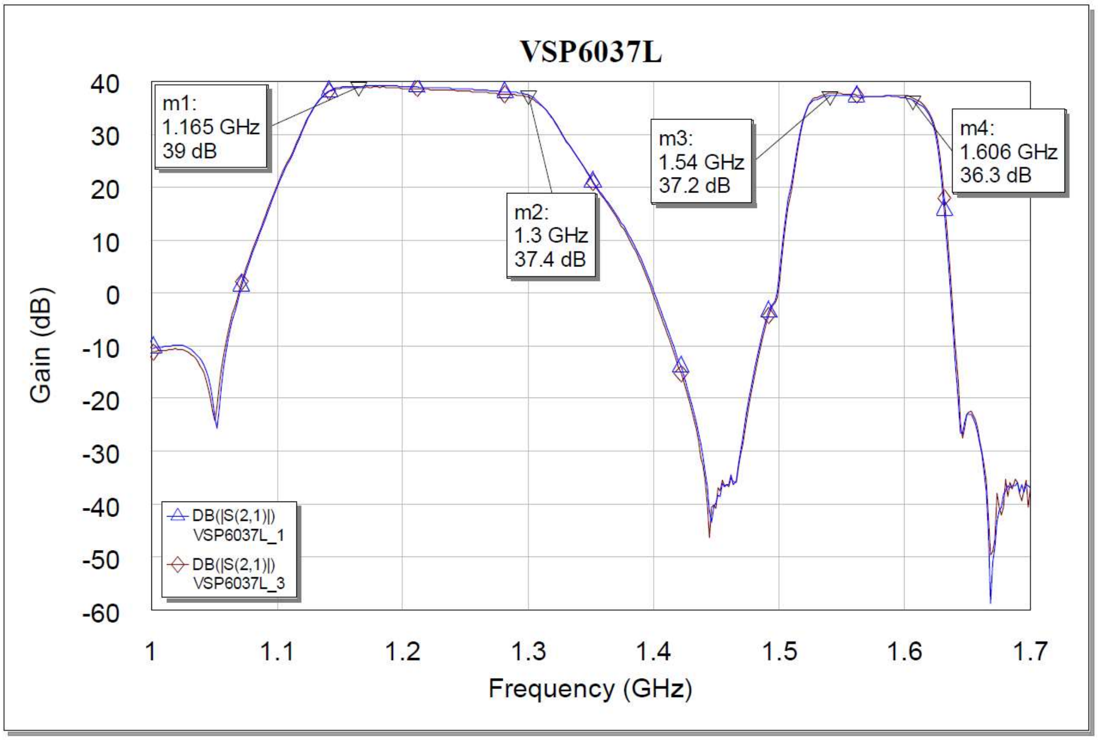
The best achievable carrier-to-noise ratio (C/N_0) for signals with marginal power flux density is limited by the efficiency of each of the antenna elements, the gain, and the overall receiver noise figure. This can be quantified by a ratio parameter, referred to as G/T, which is usually dominated by the noise figure of the input LNA. In the VeroStar^{TM} LNA design, the received signal is split into the lower GNSS frequencies (from 1160 MHz to 1300 MHz) and the higher GNSS frequencies (from 1539 MHz to 1610 MHz) in a diplexer connected directly to the antenna terminals and then pre-filtered in each band. This is where the high gain and high efficiency of the VeroStar^{TM} antenna element provides a distinct advantage, since the unavoidable losses introduced by the diplexer and filters are offset by the higher antenna gain, which preserves the all-important G/T ratio.

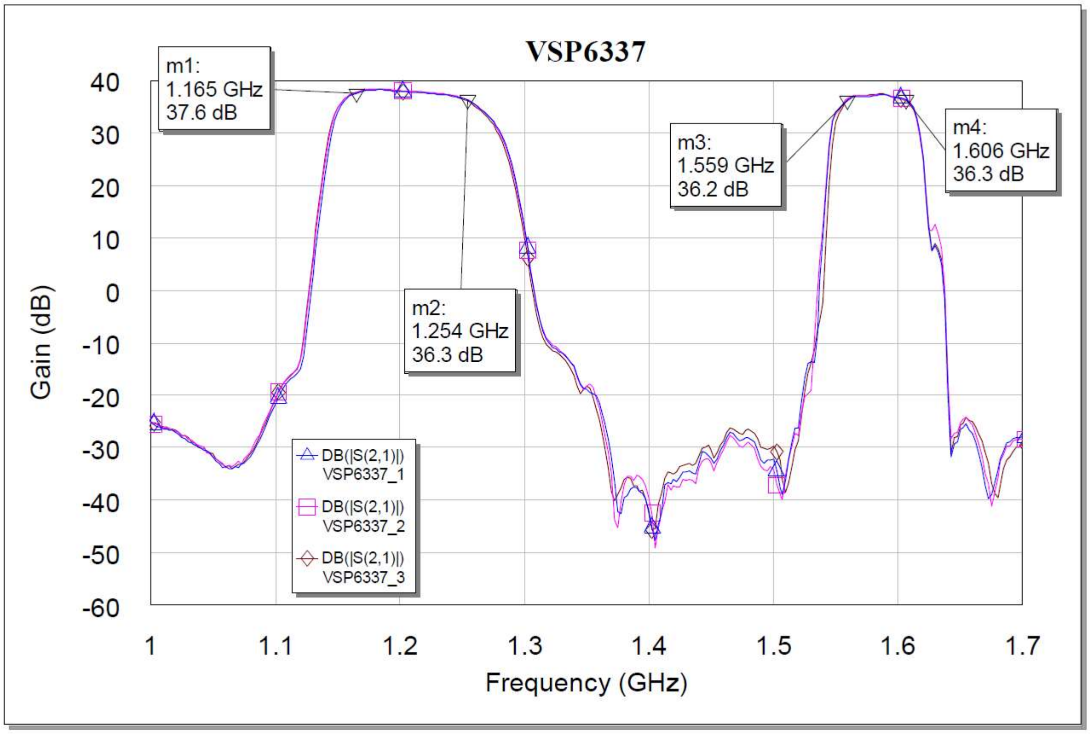
In the end, the VeroStar^{TM} LNA design is a compromise between ultimate sensitivity and ultimate interference rejection. Bear in mind that while an antenna installation might initially be determined to have no interference, subsequent introduction of new telecommunication services may change this, so interference defense is prudent even in a quiet radio frequency environment.

A first defensive measure in the VeroStar™ LNA is the addition of multi-element bandpass filters at the antenna element terminals (ahead of the LNA). These have a typical insertion loss of 1 dB because of their tight passband and steep rejection characteristics. However, the LNA noise figure is increased approximately by the additional filter-insertion loss.

The second defensive measure in the VeroStar™ LNA is the use of an LNA with high linearity. This is achieved without any significant increase in LNA power consumption by using LNA chips that employ negative feedback to provide well controlled impedance and gain over a very wide bandwidth. A potentially undesirable side effect of tight pre-filters is the possible dispersion that can result from variable group delay across the filter passband. Thus, it is important to include these criteria in selection of suitable pre-filters. The filters in the VeroStar™ LNA give rise to a maximum variation less than 10 nanoseconds in group delay over the lower GNSS frequencies (from 1160 MHz to 1300 MHz) and over the higher GNSS frequencies (from 1539 MHz to 1610 MHz).

Different filter combinations are possible to include or remove specific GNSS signals. Here is an example of the full band LNA gain versus frequency followed by another design where the E6/Be and the L-Band signal have been removed from the pass band:




VSP6337
m1:
1.165 GHz
37.6 dB
m2:
1.254 GHz
36.3 dB
m3:
1.559 GHz
36.2 dB
m4:
1.606 GHz
36.3 dB
Gain (dB)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Frequency (GHz)
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
DB(|S(2,1)|) VSP6337_1
DB(|S(2,1)|) VSP6337_2
DB(|S(2,1)|) VSP6337_3

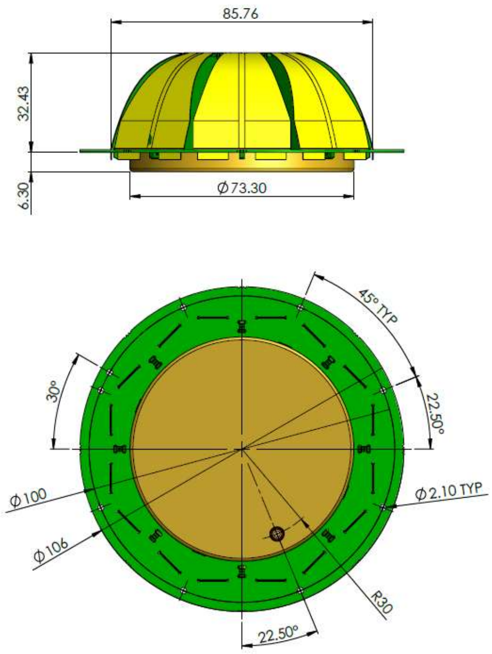
4b – VeroStar™ Mini – Design Notes and Performance Results

Introduction

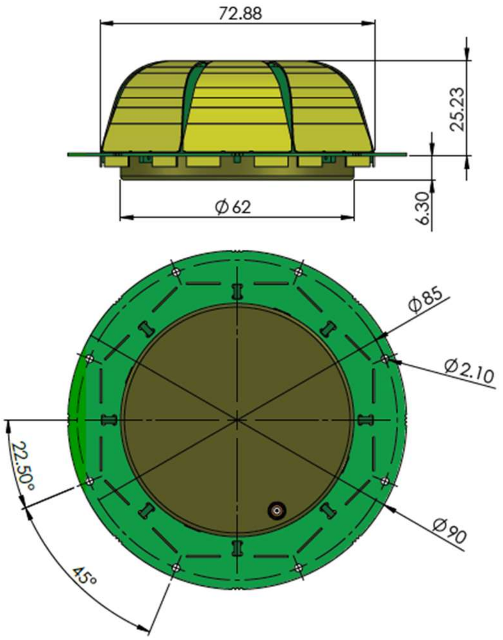
The original project plan called for an aviation housing for the super element. Subsequent work revealed both that the market for such an antenna was quite difficult to enter because of the certification requirements, and that the certification process was much more lengthy and costly than originally envisioned.

The decision was therefore made to adjust the super element design such that it could be accommodated in a standard AIRINC enclosure. This approach would circumvent the majority of certification testing while opening up the design to the aviation market.

A smaller version of the super element was built. Details can be seen below.



VeroStar Standard Element



VeroStar Mini Element

The VeroStar™'s code and phase performance was estimated using a Precise Point Positioning (PPP) application. To evaluate the antenna's ability to measure both code and phase, 3 days of data was collected for each antenna (VeroStar™ (Standard Size), VeroStar™ Mini (90mm Ground Plane-GP) and

VeroStar™ Mini (106mm GP)) and the absolute value of the GPS code and phase noise residuals were averaged.

Elevation Angle	**VeroStar**				**VeroStar Mini (90mm Ground Plane)**			
	Code Noise (M)		**Phase Noise(M)**		**Code Noise(M)**		**Phase Noise(M)**	
	C1W	**C2W**	**L1C**	**L2W**	**C1W**	**C2W**	**L1C**	**L2W**
5	0.6933	1.0440	0.0123	0.0070	0.8367	1.0930	0.0127	0.0077
15	0.8137	0.6633	0.0107	0.0063	0.8143	0.8813	0.0103	0.0063
25	0.5860	0.5767	0.0060	0.0037	0.6513	0.7917	0.0073	0.0040
35	0.5450	0.6207	0.0050	0.0030	0.6520	0.7260	0.0067	0.0040
45	0.5400	0.7103	0.0040	0.0030	0.6457	0.8133	0.0050	0.0030
55	0.5370	0.6050	0.0030	0.0020	0.5977	0.7813	0.0040	0.0027
65	0.5947	0.3860	0.0030	0.0020	0.6497	0.4543	0.0040	0.0020
75	0.4592	0.4080	0.0030	0.0020	0.4723	0.5230	0.0030	0.0020
85	0.3120	0.3290	0.0030	0.0020	0.3700	0.4783	0.0040	0.0020

Elevation Angle	**VeroStar**				**VeroStar Mini (106mm Ground Plane)**			
	Code Noise (M)		**Phase Noise(M)**		**Code Noise(M)**		**Phase Noise(M)**	
	C1W	**C2W**	**L1C**	**L2W**	**C1W**	**C2W**	**L1C**	**L2W**
5	0.6933	1.0440	0.0123	0.0070	0.6008	0.9690	0.0130	0.0075
15	0.8137	0.6633	0.0107	0.0063	0.7908	0.6755	0.0090	0.0058
25	0.5860	0.5767	0.0060	0.0037	0.6268	0.6573	0.0060	0.0033
35	0.5450	0.6207	0.0050	0.0030	0.5245	0.6525	0.0050	0.0030
45	0.5400	0.7103	0.0040	0.0030	0.4815	0.6953	0.0040	0.0025
55	0.5370	0.6050	0.0030	0.0020	0.4790	0.6065	0.0030	0.0020
65	0.5947	0.3860	0.0030	0.0020	0.5825	0.3913	0.0030	0.0020
75	0.4592	0.4080	0.0030	0.0020	0.4068	0.4178	0.0025	0.0013
85	0.3120	0.3290	0.0030	0.0020	0.2993	0.3508	0.0020	0.0010

Full test results are included with the project documentation. However, the results above show that in general, the mini element with a 106 mm ground plane has performance that rivals the standard element, and the mini element with a smaller 90 mm ground plane suffers only marginal performance degradation. In summary, the code noise for the VeroStar™ Mini (90mm GP) is between 0.1 and 0.2m higher than the VeroStar™. The noise for the VeroStar™ and the VeroStar™ Mini (106 GP) is similar.

Similarly, the phase noise for the VeroStar™ and the VeroStar™ Mini (106 GP) is more or less the same and the phase noise for the VeroStar™ Mini (90mm GP) is approximately 1mm higher.

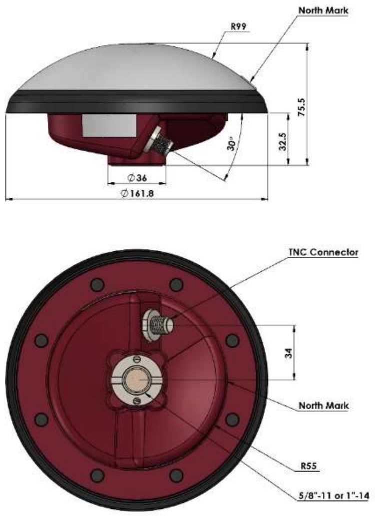
4c – VeroStar™ Housing - Design Notes and Performance Results

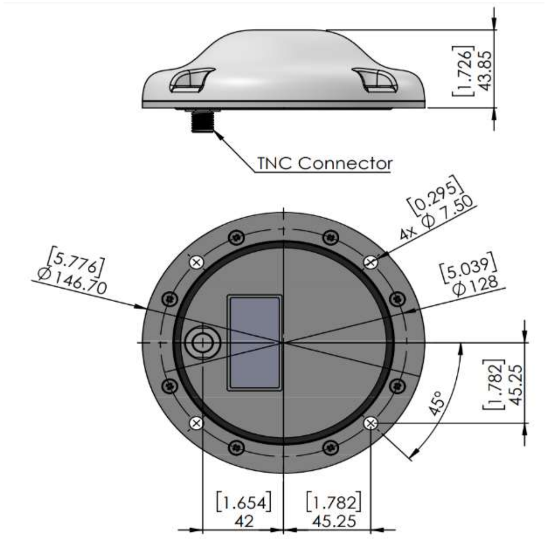
Housing

Enclosure design follows a three step process: 1) A CAD drawing of the enclosure is prepared 2) A prototype is built to check fit, operation, and clearances and 3) A mold is cut and a production version is manufactured to perform environmental and operational tests.

Because of the rigors of environmental testing, only a full production version can be used. As the project progressed it was ultimately decided to first proceed with a pole mounted housing that would address the survey market. This enclosure was designed, prototyped and manufactured from a production mold. A flat mounted housing has also been designed and prototyped. Subsequent to the end of the project the flat mounted housing was also manufactured from a production mold. Work has also started on the design of an Arinc enclosure for the VeroStar™ Mini.

Details of the two enclosures are shown below:





Environmental Testing

The production version of the survey housing was subjected to a series of environmental tests:

1- 2 m drop on asphalt and concrete
2- Mil std shock and cargo transport vibration
3- MIL-STD-810G Change 1 – Method 509.6 Salt Fog
4- IEC 60529 – IPX7 Water ingression (IP 67 rating)
5- ISO 20653:2013 -Code 9K Water ingression

Full test results are provided with the project documentation, but the enclosure passed all its tests.

5 - Market Overview

Initial market feedback for the antenna has been extremely positive. Tallysman has introduced the product under the brand name “VeroStar™” to be consistent with the Company’s current range of high precision products (VeraChoke, PCV<0.5mm, and VeraPhase, PCV, <1mm).

Highlights of the marketing efforts related to the project include:

- 250 units have been sold to date, mostly for prototype and field trials.
- The potential for the mini-super element, which will also be commercialized, is significant. Its small size means it is well suited to incorporation into phased array installations, the use of which is expected to increase as the GNSS spectrum becomes more crowded both with legitimate signals and interfering signals.
- To this end, the mini-super element has been designed into an array by a European antenna manufacturer.
- The company continues their relationship with a European receiver manufacturer who is planning to incorporate the element into a new “smart antenna”.

6 - Future Projects

The super element and the min-super element will form the core of a major product line for Tallysman. Going forward, work will continue to expand both the capabilities and the applications for the antennas. Future project work has yet to be confirmed, but potential projects the company is exploring include:

1- Continued integration into aviation applications, including drones.
2- Use in high accuracy, harsh environment military applications.
3- Work with phased array integrators using the mini super element.
4- Continued advances in overall antenna performance.